Al-Hikmah Journal of Pure and Applied Sciences
©2026
Volume 9 Issue 1: 67-76

Bacteriological and Physicochemical Quality Assessment of Drinking Water Sources in Ilorin, Nigeria

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ARTICLE INFO

Article history

Received: 15/12/2025
Revised: 23/03/2026
Accepted: 26/04/2026
Published: 08/05/2026

Doi:
https://doi.org/10.5281/zenodo.20073698

Keywords:

Antimicrobial susceptibility, WHO guidelines, Opportunistic organisms, Water safety planning Borehole, Remediation

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ABSTRACT

Guarantee on safe drinking water is indispensable for public health; quality varying across sources in Nigeria. This work assessed sachet (SW), bottled (BW), and borehole (BH) drinking water from Tanke, Ilorin, exploring physicochemical profiling, culture-based microbiology (heterotrophic, fecal coliform counts), biochemical identification, and antimicrobial susceptibility testing measure against WHO guidelines. The results on physicochemical parameters revealed acceptable pH (6.56–7.30), chloride, hardness, sulphate and nitrate. Borehole samples had electrical conductivity (1163–1175 µS/cm) exceeded guidelines values ≤1000 µS/cm), total dissolved solids at borderline-high in BH (500 mg/L), a sachet sample (SW2: 743.5 mg/L) exceeding the ≤500 mg/L limit. Critically, lead concentrations in borehole were extremely elevated (2.032–2.070 mg/L; guideline ≤0.01 mg/L), severe chemical risk implicated. Heterotrophic bacterial counts (cfu/mL), were low in all sources: SW ranged 20–40, BW ranged 0–20, and BH ranged 0–40. Biochemical characterization recovered opportunistic Gram-negative rods from borehole water (*Alcaligenes faecalis* and *Proteus vulgaris*), environmental/handling-associated taxa from sachet water (*Bacillus subtilis*, *Serratia marcescens*, *Staphylococcus aureus* and Streptomyces sp.), and commensals from bottled water (Staphylococcus sp., *Micrococcus luteus* and Streptococcus sp.). Antimicrobial testing showed widespread resistance among several isolates, including *Proteus vulgaris* and *Staphylococcus aureus*, implying environmental reservoirs of resistance. Overall, packaged waters were microbiologically acceptable, having no coliforms and very low total heterotrophic bacterial counts, but, physiochemically non-compliant (SW2 TDS). Borehole water however, presented significant chemical hazards (lead, EC) and opportunistic organisms. Findings therefore, support urgent borehole remediation, tighter sachet production controls, and continued bottled water verification, integrating antimicrobial resistance surveillance into local water safety planning.

Citation: Tomilayo, R.B., Azeez, R.T., Shitu, T. and Okwechime, P.O. (2026). Bacteriological and Physicochemical Quality Assessment of Drinking Water Sources in Ilorin, Nigeria. *AJPAS*. 9(1): 67-76

1.0 Introduction

Accessibility to safe drinking water is crucial to human right and pillar of public health. Yet, the quality of drinking water remains highly variable across sources (sachet, bottled, and borehole) supplies in many developing countries; Nigeria inclusive. Based on the World Health Organization (WHO) emphasis; water intended for human consumption must be free from harmful chemical contaminants and pathogenic microorganisms, as both categories pose significant risks to health and well-being [1]. Despite this, widespread contamination in Nigerian water systems, were revealed from continuous studies; reflecting infrastructural deficits, poor regulation, and anthropogenic pressures.

In recent findings, dual challenges of physicochemical and microbiological safety in Nigerian drinking water were revealed. Groundwater and table water sources in Enugu urban centers were observed to exceed permissible limits for electrical conductivity and selected heavy metals, associated with human health and ecological risks [2]. Likewise, a Water Safety Plan–based study in Aba revealed how dysfunctional waterworks and unregulated urban practices threaten water quality, confirming elevated risks from both chemical and bacteriological parameters [3]. The aforementioned findings thus stress the urgent need for defined pattern of monitoring and remediating community water sources.

Heavy metal contamination (lead, arsenic and cadmium), emerged as a critical concern in borehole water across Nigeria. Comparative assessments in Akure raised alarms about chronic exposure risks through unsafe concentrations of lead and cadmium in well and borehole water [4]. Also, spatio-temporal studies in Taraba State reported elevated levels of lead and chromium in borehole water, with seasonal variations aggravating contamination [5]. In addition, borehole water was found to contain multiple heavy metals above WHO thresholds in Uyo Metropolis; further confirming the exposure of groundwater sources to geogenic and anthropogenic pollution [6].

Aside chemical hazards, microbial contamination as well remains a persistent alarm. Packaged water, often entrusted safer, has been shown to harbor opportunistic organisms due to oversight in production hygiene and storage practices. A review of drinking water quality across Nigeria affirmed microbial contamination widespread; coliforms and opportunistic pathogens often detected in sachet and bottled water [7]. In recent studies from Southern Nigeria, antibiotic-resistant bacteria from surface waters used in domestic activities were often identified, and these include multidrug-resistant strains resistant to ampicillin, tetracycline, and ciprofloxacin [8].

The intersection of water quality and antimicrobial resistance (AMR) is particularly concerning. Environmental reservoirs of resistant bacteria and antibiotic residues thus might create pathway to the persistence and dissemination of resistance genes. It was emphasized that Nigeria's water systems are increasingly burdened by antibiotic resistance [9], a major threat to public health challenge and impeding progress toward Sustainable Development Goals (SDGs). Environmental antibiotic residues detected in wells, rivers, abattoir wastewater, and even bottled water, further highlighted the ubiquity of AMR risks in water sources [10].

1.2 Statement of the problem

Trust in the consumption of sachet, bottled, and borehole water by the communities in Ilorin, Kwara State has become a routine. However, restricted monitoring and regulatory lapse of these water sources raised concerns about chemical safety, microbial contamination, and antibiotic-resistant organisms, thus, creating risks to public health and progress toward Sustainable Development Goals 3 and 6.

1.3 Rationale and aims

This study comparatively assess the physicochemical quality, bacteriological status, and antimicrobial susceptibility of sachet, bottled, and borehole drinking water within Tanke community, Ilorin. Comparing the results with World Health Organization standards, the study aims to identify health risks and support improved water safety management combined with public health policy.

2.0 Materials and Method

2.1 Sampling

Three (3) brands of bottled water (coded BW1, BW2 and BW3), three brands of sachet water (coded SW1, SW2 and SW3) were purchased from retail outlets within Tanke community, Ilorin, Nigeria. Borehole water samples were collected from three different borehole sources within the same community. Sampling was conducted once monthly over a three-month period (February, April, and June), spanning the late dry season and the onset of the rainy season, with approximately one-month intervals between sampling events. Samples were transported aseptically to the laboratory and analyzed within 24 hours of collection following standard procedures [11,12]

2.2 Materials Used

Sterile laboratory consumables (Petri dishes, test tubes, inoculating loops, McCartney bottles, Durham tubes, syringes, slides, cover slips) and analytical equipment (pH meter, thermometer, autoclave, incubator, conductivity meter, turbidimeter, microscope) were used. Several reagents used included: $AgNO_3$, $Na_2S_2O_3$, $MnCl_2$, EDTA, potassium chromate, starch indicator, and standard biochemical test reagents.

Culture media employed were Nutrient Agar (NA) for total bacterial count, selective (MacConkey and Mannitol Salt) Agar for fecal coliform and E. coli counts as pollution indicator organism. Triple Sugar Iron Agar (TSI), Sulphide-Indole-Motility (SIM), Methyl Red–Voges Proskauer (MR-VP), Mueller Hinton Agar (MHA), and biochemical reagents (catalase, oxidase, citrate, urease, Kovac's reagent). Media preparation and sterilization were based on manufacturer's instructions and APHA guidelines [12]. All the microbiological analysis were done under aseptic conditions [1].

2.3 Physicochemical Parameters

2.3.1 Organoleptic Properties

About 20 mL aliquot of each sample was examined visually for Colour, odour, and taste using sensory evaluation methods for acceptability [11].

2.3.2 Temperature and pH

Temperature was measured using a calibrated mercury thermometer, while pH was determined using a handheld digital pH meter standardized with buffer solutions [12].

2.3.3 Others

Chloride was determined by argentometric titration using $AgNO_3$ and potassium chromate indicator [12]. Total Hardness was by complexometric titration with EDTA using Eriochrome Black-T indicator [13]; Chemical Oxygen Demand (COD) determined by open reflux method with $K_2Cr_2O_7$ digestion and titration against ferrous ammonium sulphate [12]. Salinity was assessed by using Mohr's method with $AgNO_3$ titration [14]; Biochemical Oxygen Demand (BOD) was analyzed by Winkler's method following SON standards [11]. Turbidity was measured using ISO 7027 standard with a calibrated turbidimeter [1] while dissolved oxygen (DO) was evaluated by Winkler titration method [12]. Total Dissolved Solids (TDS) was measured gravimetrically by evaporating filtered samples at 180 °C based on the method of Nwachukwu et al. [15] and electrical conductivity (EC) measured using a calibrated conductivity meter [12]. Nitrate was determined using the UV–visible spectrophotometric cadmium reduction method, and sulphate by the barium chloride turbidimetric method, following APHA standards, the heavy metals analyzed was determined by Atomic Absorption Spectrometry (AAS) [14].

2.4 Microbiological analysis

2.4.1 Bacterial Isolation

Total heterotrophic bacteria were enumerated using the standard spread plate method. With the aid of a sterile pipette, one ml of the water sample was directly seeded onto labeled plates containing sterile nutrient agar and swirled to ensure proper mixing of the sample with the medium. The plates were set and incubated at 37^{o}C for 24 hours. After which the plates were observed for growth, discrete colonies were enumerated, characterized and recorded in cfu/ml of water [16-18]. All samples were analyzed in

duplicates on Nutrient agar, while total and fecal coliforms were quantified using the three (3) tubes assay of the Most Probable Number (MPN) technique [18].

2.4.2 Characterization and Identification of Isolates

Bacterial isolates were characterized and identified by using Bergey's Manual of Systematic Bacteriology and recent water microbiology protocols [19].

2.5 Antimicrobial Susceptibility Testing (AST)

Antimicrobial susceptibility of isolates was determined using the Kirby-Bauer disk diffusion method on Mueller-Hinton agar. Inhibition zones were measured and interpreted according to CLSI (2023) breakpoints [20]. EUCAST (2023) guidelines were consulted for reference, but CLSI breakpoints were used for all interpretations.

3.0 Results

3.1 Physicochemical Quality of the Water Samples

The physicochemical properties of the sachet water samples ranged from 33.0 – 34.0 ^{O}C, 6.93 – 7.18, 169.4 – 743.5 mg/l, 147.7 – 396.5 µs/cm, 34.40 – 55.20 mg/l, 9.014 – 39.922 mg/l, 26.231 – 35.486 mg/l and 5.656 – 29.502 mg/l for temperature, pH, total dissolved solids, electrical conductivity, dissolved oxygen, total hardness, chloride ion, and magnesium hardness respectively. Colour, taste and odour were not detected in all the sachet water samples analysed (Table 1).

The physicochemical properties of the bottled water samples ranged from 35.0 – 36.0 ^{O}C, 6.56 – 7.30, 231.0 – 390.0 mg/l, 453.0 – 785.0 µs/cm, 31.20 – 32.80 mg/l, 5.151 – 9.014 mg/l, 21.979 – 24.813 mg/l and 3.547 – 5.659 mg/l for temperature, pH, total dissolved solids, electrical conductivity, dissolved oxygen, total hardness, chloride ion, and magnesium hardness respectively. Colour, taste and odour were also not detected in all the bottled water samples analysed (Table 2).

The physicochemical properties of the borehole water samples ranged from 29.25 – 29.45 ^{O}C, 6.67 – 6.69, 500.3 – 500.7 mg/l, 1163 – 1175 µs/cm, 75 – 83 mg/l, 35.80 – 36.00 mg/l, 23.68 – 23.82 mg/l and 29 – 33 mg/l for temperature, pH, total dissolved solids, electrical conductivity, dissolved oxygen, total hardness, chloride ion, and magnesium hardness respectively. Colour, taste and odour were not detected in all the sachet water samples analysed (Table 3). Other physicochemical parameters such as biological oxygen demand (BOD), Chemical oxygen demand (COD), Salinity, Turbidity, Sulphate ion, Nitrate ion and Calcium hardness respectively ranged from 40.22 – 40.66 mg/l, 0.79 – 0.99 mg/l, 0.01 – 0.03%, 0.17 – 0.21 mg/l, 30.45 – 32.49 mg/l, 0.60 – 0.82 mg/l and 3.70 – 6.10 mg/l (Table 4).

Some selected metals were also detected in the borehole water samples ranging from 2.032 – 2.070 mg/l, 3.547 – 4.457 mg/l, 6.514 – 6.894 mg/l and 0.803 – 0.817 mg//l for lead (Pb), calcium (Ca), magnesium (Mg) and iron (Fe) respectively (Table 5).

3.2 Microbiological analysis

Table 6 shows the total bacterial counts of 20 - 40 cfu/ml in Sachet water, 0 – 20 cfu/ml in bottled water and 0 - 40 cfu/ml in borehole water. Coliforms counts were zero in all the samples. The cellular and morphological characteristics of the bacterial isolates were represented in Table 7 and the biochemical characteristics for the bacterial identification based on the production of certain enzymes, motility and fermentation of certain sugars were presented in Table 8.

3.3 Antimicrobial Susceptibility Testing (AST)

Antimicrobial susceptibility testing revealed widespread resistance among bacterial isolates recovered from sachet, bottled, and borehole water samples (Table 9). It was observed that *Proteus vulgaris* and *Serratia marcescens* were resistant to multiple fluoroquinolones and cephalosporins, however, *Staphylococcus aureus* and *Micrococcus luteus* displayed consistent resistance to penicillins and macrolides. Highest resistance rates (>90%) were observed with Ampicillin and amoxicillin/clavulanate, while azithromycin and

cloxacillin were >70% but Cephalosporins and gentamicin exhibited lowest rates resistance, fluoroquinolones however, displayed inconsistency rates across the isolates. These trends are summarized in Figure 1, whereby the predominance of resistance to β-lactams and macrolides were highlighted, aboard multidrug resistance in the reported Gram-negative rods. Table 9 and figure 1 accent the role of community in drinking water sources as lakes of antimicrobial resistance; therefore, necessitates continuous surveillance.

Table 1: Physicochemical Properties of Sachet Water Samples

Sample	Physicochemical Parameters									
	Colour	**Taste & Odour**	**Temp ^{0}C**	**pH**	**Total Dissolved Solids (mg/l)**	**Electric Conductivity(µs/cm)**	**Dissolved Oxygen (mg/l)**	**Total Hardness (mg/l)**	**Chloride ion (mg/l)**	**Magnesium Hardness (mg/l)**
SW1	None	None	34.0	6.99	203.5	396.5	55.20	39.922	35.486	29.502
SW2	None	None	33.0	7.18	743.5	147.7	42.40	32.192	26.231	24.981
SW3	None	None	34.0	6.93	169.4	342.0	34.40	9.014	29.039	5.656
WHO Standard	None	None	Typically ambient	6.5-8.5	≤500mg/L	≤1000µs/cm	≥5mg/L	≤300mg/L	≤250mg/L	≤50mg/L

Values are in mean of triplicates samples

Table 2: Physicochemical Properties of Bottled Water Samples

Sample	**Physicochemical Parameters**									
	Colour	**Taste & Odour**	**Temp ^{0}C**	**pH**	**Total Dissolved Solids (mg/l)**	**Electric Conductivity (µs/cm)**	**Dissolved Oxygen (mg/l)**	**Total Hardness (mg/l)**	**Chloride ion(mg/l)**	**Magnesium Hardness (mg/l)**
BW1	None	None	36.0	6.56	231.0	453.0	31.20	9.014	24.813	5.659
BW2	None	None	35.0	7.30	390.0	785.0	32.80	5.151	21.979	3.547
BW3	None	None	35.5	6.75	352.0	568.0	32.60	6.025	22.789	4.564
WHO Standard	None	None	Typically ambient	6.5-8.5	≤500mg/L	≤1000µs/cm	≥5mg/L	≤300mg/L	≤250mg/L	≤50mg/L

Values are in mean of triplicates

Table 3: Physicochemical Properties of Borehole Water Samples

Sample	Physicochemical Parameters									
	Colour	Taste & Odour	Temp ^{0}C	pH	Total Dissolved Solids (mg/l)	Electric Conductivity (µs/cm)	Dissolved Oxygen (mg/l)	Total Hardness (mg/l)	Chloride ion (mg/l)	Magnesium Hardness (mg/l)
BHW1	None	None	29.35	6.69	500.5	1169	79	35.90	23.75	31
BHW2	None	None	29.25	6.67	500.7	1163	75	36.00	23.68	29
BHW3	None	None	29.45	6.71	500.3	1175	83	35.80	23.82	33
WHO Standard	None	None	Typically ambient	6.5-8.5	≤500mg/L	≤1000µs/cm	≥5mg/L	≤300mg/L	≤250mg/L	≤50mg/L

Values are in mean of triplicates samples

Table 4: Other Physiochemical Characteristics of the Borehole Water Samples

Sample	**Physicochemical parameters values**							
	DO (mg/l)	**BOD (mg/l)**	**COD (mg/l)**	**Salinity %**	**Turbidity (NTU)**	**Sulphate ion (mg/l)**	**Nitrate ion (mg/l)**	**Calcium hardness (mg/l)**
BHW1	79	40.44	0.89	0.01	0.19	31.47	0.71	4.90
BHW2	76	40.22	0.79	0.03	0.21	30.45	0.82	3.70
BHW3	82	40.66	0.99	0.02	0.17	32.49	0.60	6.10
WHO standard	-	-	-	-	-	250	≤50	≤500

Values are in mean of triplicates. DO=Dissolved Oxygen; BOD=Biological Oxygen Demand; COD=Chemical Oxygen demand; (-)=Not specific

3.2 Some Selected Metal Content in Borehole water samples

Table 5: Analyzed Metals in borehole water samples

Samples	**Quantity Metals (Mg/l)**

	Lead (Pb)	Calcium (Ca)	Magnesium (Mg)	Iron (Fe)
BHW1	2.051	3.547	6.704	0.817
BHW2	2.032	4.457	6.514	0.803
BHW3	2.070	4.457	6.894	0.810
WHO standard	≦ 0.01	≧20; ≦40-80	Hardness value	Aesthetic value

Values are in mean of triplicates samples. SW1-SW3=Sachet water sample 1-3; BW1-BW3=Bottled water sample 1-3; BHW1-BHW3=Borehole water sample 1-3

3.3 Microbiological Quality

Table 6: Total bacterial count of the Sachet, Bottled and Borehole Water Samples

Samples	Total coliform MPN/100ml	Fecal coliform MPN/100ml	Heterotrophic bacterial counts (cfu/ml)
SW1	0	0	40
SW2	0	0	30
SW3	0	0	20
BW1	0	0	20
BW2	0	0	0
BW3	0	0	10
BHW1	0	0	40
BHW2	0	0	0
BHW3	0	0	20

Keys: (SW) - Sachet water; (BW) - Bottled water; BHW - Bore hole water. Values are in mean of triplicates samples

Table 7: Cellular and Morphological Characteristics of the Isolates

Code	Shape	Edge	Colour	Elevation	Size	Colonial surface
NABH1	Irregular	Undulate	Cream	Flat	Medium	Moist, smooth, non-swarming, -ve rod
NABH2	-	-	-	-	-	No growth
NABH3	Irregular	Entire	Yellowish	Raised	Large, spread	Moist, Gram -ve rod
MABH4	-	-	-	-	-	No growth
SW1NA	Circular	Entire	Milky (dull)	Flat	Large,Swarming	Dry, Gram +ve, long straight rod
SW2NA1	Irregular	entire	Milky, Dull	Flat	Large, swarming	Dry Gram +ve, long staight rod
SW2NA2	Circular	Entire	Milky , Dull	Flat	Large, swarming	Dry, Gram +ve, long staight rod
SW3NA	Cicular	Entire	Milky, Dull	Flat	Medium, swarming	Dry, Gram +ve, long staight rod
BW1NA	Circular	Smooth, Entire	Milky	Raised	Small	-ve, Bacilli
BW2NA	-	-	-	-	-	No growth
SW1MAC	Irregular	Undulate	Pink, Shiny	Raised	Small	Gram -ve; rod
SW2MAN1	Irregular	Undulate	Dull Milky	Flat	Small	Dry, +ve Bacilli
SW2MAC2	Irregular	Undulate	Pink	Flat	Large, spread	Moist, Gram -ve short rod
SW3MAN	Circular	Entire	Dull, Milky, Transparent	Flat	Large, Swarming	Dry, Gram +ve long straight rod
BW1MAN1	Circular	Entire	Milky	Flat	Small	+ve Cocci in cluster of spherical cells
BW1MAN2	Circular	Entire	Dull, Pink	Raised	Small	Dry, +ve Cocci in tetrads of spherical cells
BW2MAC	-	-	-	-	-	No growth
SW1MAN	Circular	Entire	Dull, Milky	Flat	Large swarming	Dry, Gram +ve long straight rod
SW2MAN	Circular	Entire	Dull Yellow, Opaque	Raised	Small	Dry, +ve cocci , with branching chain of cells
SW3MAN	Circular	Entire	Dull Yellow, Opaque	Flat	Small	+ve Cocci
BW1MAN1	Circular	Entire	Milky, Shiny	Raised	Medium	+ve Cocci
BW1MAN2	Circular	Entire	Pink, Opaque, Shiny	Raised	Medium	+ve Cocci
BW2MAN	-	-	-	-	-	No growth

Table 8: Biochemical Characteristics of the Isolates from the Drinking water

Codes	Cat	Oxid	Cit	H2S	Gas	Gluc	Lac	Suc	Ind	Urea	MR	VP	Mot	Probable Organisms
SW1MAC	+	+	-	+	-	+	+	+	-	+	-	-	+	*Methylobacterium* sp

SW1	+	-	+	-	-	+	+	+	-	+	-	-	+	*Bacillus subtilis*
SW2MAC2	+	-	+	-	-	+	-	+	+	+	+	-	+	*Serratia marscens*
SW2	+	-	+	-	-	+	+	+	-	+	-	-	+	*Bacillus subtilis*
BW1MAN1	+	-	-	-	-	+	+	+	-	+	-	-	-	*Staphylococcus* sp.
BW1MAN2	+	+	-	-	-	+	+	+	-	+	-	-	-	*Micrococcus luteus*
SW3	+	-	+	-	-	+	+	+	-	+	-	-	+	*Bacillus subtilis*
SW2MAN	+	+	-	-	-	-	-	-	-	+	-	-	-	Streptomyces
SW3MAN	+	-	-	-	-	+	+	+	-	-	-	-	-	*Staphylococcus aureus*
BW1MAN1	-	-	-	-	-	+	+	+	+	+	-		-	*Streptococcus* sp.
BW1MAN2			-	-	-	+	+	+	-	+	-		-	*Micrococcus* sp.
NBH1	+	+	+	-	-	-	-	-	-	+	-	+	+	*Alcaligenes faecalis*
NBH3	-	+	+	+	+	+	-	+	+	+	+	-	+	*Proteus vulgaris*

3.4 Antimicrobial Susceptibility

Table 9: Antimicrobial susceptibility of bacterial isolates from water samples (sachet, bottled, and borehole)

S/N	Isolates	CPX	LEV	OFX	SP	PEF	AZ	CF	CN	PX	R	AM	AV
1.	***Methylobacterium* sp.**	R	R	R	R	R	R	I	R	R	S	R	R
2.	***Bacillus subtilis***	R	R	R	R	R	R	R	R	R	S	R	R
3.	***Serratia marscens***	R	R	R	R	R	R	R	R	R	S	R	R
4.	***Bacillus subtilis***	R	R	R	R	R	R	R	R	R	S	R	R
5.	***Staphylococcus* sp.**	I	I	R	I	S	S	S	R	S	S	R	R
6.	***Micrococcus luteus***	R	R	R	R	R	R	R	R	I	S	R	R
7.	***Bacillus subtilis***	R	R	I	I	R	S	S	I	S	I	R	R
8.	***Streptomyces***	R	R	I	R	S	S	S	R	S	S	R	R
9.	***Staphylococcus aureus***	R	R	S	S	S	S	S	S	S	S	R	R
10.	***Streptococcus* sp**	R	R	S	S	S	S	S	S	S	S	R	R
11.	***Micrococcus* sp**	R	R	S	S	S	S	S	S	S	S	R	R
12.	***Alcaligenes faecalis* (NABH1)**	R	R	R	I	R	I	I	R	R	I	S	S
12.	***Proteus vulgaris* (NABH3)**	R	R	I	R	R	R	R	R	R	R	S	S

Key: CPX = Ciprofloxacin; LEV = Levofloxacin; OFX = Ofloxacin; SP = Sparfloxacin; PEF = Pefloxacin; AZ = Azithromycin; CF = Cefuroxime; CN = Gentamicin; PX = Cloxacillin; AM = Ampicillin; AV = Amoxicillin/Clavulanate. R = Resistant (no inhibition zone); I = Intermediate; S = Susceptible. Interpretations are based on CLSI breakpoints.

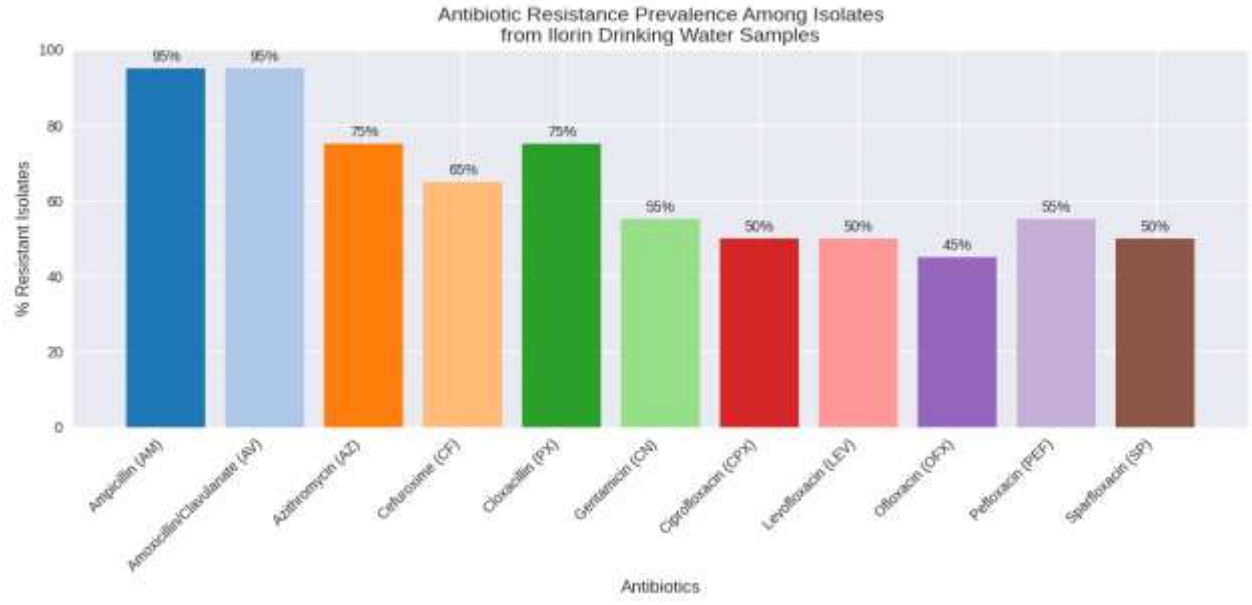

Figure 1: Prevalence of antibiotic resistance among bacterial isolates recovered from sachet, bottled, and borehole water samples within Tanke community, Ilorin.

4.0 Discussion

4.1 Physicochemical Quality

Most parameters such as pH (6.56–7.30), hardness, chloride, and magnesium were within WHO limits, consistent with findings from Ajala *et al.* [21] who reported general compliance of packaged water in Nigeria. However, borehole water showed elevated electrical conductivity (1163–1175 µS/cm) and lead concentrations (2.03 mg/L) far above permissible limits (0.01mg/l). Similar exceedances were documented in Taraba State by Hamman and Inda [5], who found borehole water to be contaminated with heavy metals (Pb and Cd). Ojo [4], who compared heavy metals in well and borehole water highlighted heavy metal risks in Akure boreholes. Azubuike *et al*. [22] reported acidic borehole water in Owerri; elevated levels of heavy metals (Ni, and Cr; Pb and As), total dissolved solids (TDS) with microbial contamination from varying locations, implied, potential health risks and needs for treatment before consumption. In contrast, bottled water in this study was largely compliant, aligning with Jimoh *et al.* [23], who observed better physicochemical stability in bottled water compared to sachet brands in Ilorin. The findings thus implied groundwater contamination by geogenic sources or anthropogenic inputs remains a widespread issue in Nigeria.

4.2 Microbiological Quality

The absence of fecal coliforms across all samples is encouraging and mirrors findings from Magaji [24], who reported low coliform counts in sachet water brands in Abuja. Results from recent borehole surveys in Nigeria as well revealed only heterotrophic bacteria presence [25]. Nevertheless, opportunistic isolates: *Proteus vulgaris* and *Alcaligenes faecalis* recovered from the borehole water, indicated environmental contamination; consistent with Hamman and Inda [5] and Azubuike *et al*. [22] who reported opportunistic Gram-negative rods in rural boreholes. *Bacillus subtilis* was observed to be prevalent in two of the sachet water samples, this might be due to its spore formation ability and as wellbeing an opportunistic organism. In support of the latter finding, packaged water isolates; *Bacillus subtilis* and *Serratia marcescens*, echoing Ajala *et al.* [21], who highlighted contamination risks from poor handling and storage of sachet water.

4.3 Morphological and Biochemical Profiles

Microbial contamination in the drinking water sources in this research agreed with various recent researchers: the detection of *Proteus vulgaris* in borehole water is significant; linked to fecal contamination and opportunistic infections. Jimoh *et al.* [23] similarly reported opportunistic Enterobacteriaceae in sachet water sold in Ilorin. However, in contrast to this finding, [17] discovered two (2) of his twenty (20) sampled sachet water contaminated with coliforms; of which, one showed high coliform count of 43MPN/100ml which far exceeded WHO and Nigerian standard for drinking water Quality (NSDWQ) permissible limit of 0 MPN/100ml for total coliforms in drinking water. Bottled water isolates were mainly commensals (*Staphylococcus*, *Micrococcus*), aligned with Ajala *et al.* [21]; attributed to handling contamination rather than source water quality. Abdulmutallab and Muhammad [16] in their findings recorded significant microbial contamination in the sampled boreholes in Wuse, Abuja; he observed that 80% of his samples failed to meet microbial safety standards, thus, emphasized the need for water treatment and regular monitoring. However, packaged water appears microbiologically safer, it is not sterile, thus, requires strict hygiene during production and distribution.

4.4 Antimicrobial Susceptibility

Resistance patterns observed in this study, particularly in *Proteus vulgaris* and *Staphylococcus aureus*, reflect broader concerns about antimicrobial resistance reservoirs in environmental waters. Jimoh *et al.* [23] noted similar resistance trends in isolates from packaged water in Ilorin, while Hamman and Inda [5] emphasized that borehole water often harbors resistant Gram-negative bacteria. Chukwuka *et al.* [26] as well reported resistant pathogens in packaged water in Delta State, while Rabiu *et al.* [27] found *E. coli* with transmissible AMR genes in household water in Ibadan. Popoola *et al*. [28] further

demonstrated multidrug resistance in river water isolates in Oyo State. Even though, limited sampling was involved in this research while the mean values of the triplicate samples were employed; yet, the findings revealed the role of community water sources in the environmental spread of AMR, as agreed with our observation that borehole isolates showed resistance to multiple antibiotics.

Hence, revealing chemical hazards and microbial contaminants with implicated public environmental health risk and antimicrobial resistance in community water sources, this study evaluates the need for urgent integration of water safety planning and AMR surveillance, for Sustainable Development Goal 3 (Good Health and Well-Being) and Sustainable Development Goal 6 (Clean Water and Sanitation).

5.0 Conclusion

This study assessed the physicochemical and microbiological quality of sachet, bottled, and borehole water within the Tanke community of Ilorin, Nigeria. The results revealed a significant pointer: even though some parameters (pH, hardness, and chloride) met the WHO standards, borehole water consistently revealed critical chemical exceedances; electrical conductivity and lead concentrations far above permissible limits. Even though, microbiological analysis confirmed across all sources; devoid of fecal coliforms, yet borehole water had heterotrophic counts and opportunistic organisms (*Proteus vulgaris* and *Alcaligenes faecalis)*. In general, packaged waters (sachet and bottled) appeared safer, sachet water occasionally exceeded TDS limits and was contaminated with environmental bacteria. The presence of resistant strains as highlighted by the antimicrobial susceptibility test, underscored the community water sources as reservoir of antimicrobial resistance.

Conclusively, packaged water in Tanke community confirm comparative safety; significant chemical and microbial risks evaluated from borehole water demand urgent intervention. Thus, motivation to strengthening regulatory oversight, improving source protection, and embedding antimicrobial resistance surveillance into water safety planning are faultfinding paths toward safeguarding public health. This finding provides supportive evidence to guide policy, regulation, and community action for safer drinking water in Ilorin and related municipality within Nigerian communities.

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