

Bacteriological and Physicochemical Assessment of Borehole in Gindin Dorowa, Wukari Local Government Area, Taraba State, Nigeria

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ABSTRACT

Groundwater from boreholes constitutes the primary source of domestic water in many rural communities of Nigeria. This study assessed the bacteriological and physicochemical quality of borehole water in Gindin Dorowa, Wukari Local Government Area, Taraba State, Nigeria. Water samples were collected in triplicate from three boreholes in Angwan Burofi (N07°52'15.3" E009°47'12.1"), Angwan CRCN Hospital (N07°52'21.8" E009°47'18.6") and Angwan Sabon Kasuwa (N07°52'28.4" E009°47'25.2"), Gindin Dorowa (central coordinate: 7.8704°N, 9.7785°E), using sterile sample containers. Standard microbiological procedures, including serial dilution, pour plate technique, Gram staining, colony morphology, and biochemical characterization (catalase, coagulase, indole, methyl red, citrate utilization, oxidase) were employed for bacterial isolation and identification. Physicochemical parameters comprising pH, temperature, electrical conductivity, turbidity, total dissolved solids (TDS), and dissolved oxygen (DO) were determined using standard analytical methods recommended by WHO and UNICEF, with each method described separately. Results showed total viable counts ranging from 2.0×10^6 cfu/ml (Angwan Sabon Kasuwa) to 2.6×10^6 cfu/ml (Angwan CRCN Hospital), far exceeding WHO/SON limit of $<1 \times 10^2$ cfu/ml. Five bacterial species were isolated: *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Shigella* spp., and *Staphylococcus aureus*, with *E. coli* indicating recent faecal contamination. Physicochemical analysis revealed pH values of 6.1-6.7 (below WHO 6.5-8.5), turbidity 40-56 NTU (above WHO ≤ 5 NTU), while electrical conductivity (19.6-30.1 $\mu\text{S}/\text{cm}$) and TDS (428.6-474.1 mg/L) were within WHO limits (1000 $\mu\text{S}/\text{cm}$ and 500 mg/L respectively). The borehole water is severely contaminated and unfit for consumption without treatment.

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INTRODUCTION

Water is the most vital compound for all living organisms, sustaining ecological balance and human survival. Water constitutes a considerable portion of the weight of living organisms (Chakraborty, 2021). On a larger scale, water is the most abundant compound on Earth, covering over 75% of the planet's surface (Ibearugbulam *et al.*, 2021). However, despite its vast abundance, the majority of this water is saltwater, which is unsuitable for human consumption and most agricultural purposes (Akib Javed *et al.*, 2020). Only a small fraction of the Earth's water is readily accessible for human use.

Water is among the most poorly managed and overused natural resources globally (Dhaouadi *et al.*, 2021). Groundwater obtained from boreholes and wells remains a major source of drinking and domestic water, particularly in areas where surface water is limited or polluted. Unfortunately, the pressures of rapid population growth, industrial expansion, and intensified agriculture have increased groundwater contamination through hazardous physicochemical and biological pollutants (Ukaogo *et al.*, 2020). The mismanagement of water resources, combined with rising industrialization and pollution, has intensified the global water crisis, leaving over 1 billion people without access to safe drinking water (Martínez-Santos, 2017). This poses serious public health risks, as unsafe water is a leading cause of diseases such as cholera and dysentery, especially in developing nations (Kristanti *et al.*, 2022).

The physicochemical and biological properties of water are closely linked and largely influenced by surrounding land use, which shapes the quality of water entering freshwater streams (Hamid *et al.*, 2020). Human-induced eutrophication of water bodies has intensified the need for interventions aimed at restoring and maintaining water quality (Wu *et al.*, 2021). Harmful physicochemical pollutants, including heavy metals such as Pb^{2+} , Fe^{2+} , and Ni^{2+} , along with excessive nitrates from agricultural runoff and industrial discharges, pose long-term health hazards, including chronic toxicity, organ damage, and cancer risks (Kumar *et al.*, 2019). Similarly, microbiological contaminants like *Escherichia coli* and total coliforms present serious threats by causing waterborne diseases such as cholera and dysentery (Bhatt and Srinivasan, 2019).

Water quality is a critical issue for humanity because it has a direct impact on human health and well-being. Although groundwater is often considered cleaner than surface water, its quality is influenced by both natural geological factors and human activities such as water extraction, land use changes, and improper waste disposal (Garba *et al.*, 2018). The safety of drinking water is assessed through physicochemical and microbiological parameters, making their analysis essential for public health protection and pollution monitoring (Garba *et al.*, 2018). Physical tests evaluate characteristics like temperature, colour, odour, pH, turbidity, and total dissolved solids (TDS), while chemical tests focus on biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved

oxygen, alkalinity, and hardness. To ensure higher purity, water is also examined for trace metals, heavy metals and organic compounds (Singh *et al.*, 2017). In developed nations, these standards are closely regulated, but in many regions, strict monitoring is limited. Moreover, detecting very low concentrations of heavy metals requires advanced analytical instruments and skilled personnel (Pathan *et al.*, 2018).

Safe drinking water is essential for public health, yet groundwater quality is increasingly threatened by poor sanitation, agricultural activities, and indiscriminate waste disposal. Boreholes and wells are the major sources of domestic water in many Nigerian communities, including Gindin Dorowa, where information on water quality remains limited. Evaluating the bacteriological and physicochemical characteristics of these water sources is therefore necessary to determine their suitability for human consumption and to identify potential public health risks associated with groundwater contamination.

MATERIALS AND METHODS

Study Area

The study was conducted in Gindin Dorowa, Wukari Local Government Area of Taraba State, Nigeria. Central coordinate: Latitude 7.87040° N, Longitude 9.77851° E. Tropical continental climate, wet season April-October (1000-1500 mm rainfall), dry season November-March, temperature 20-40°C. Water samples were collected from three borehole locations (Angwan Burofi- N07°52'15.3" E009°47'12.1", Angwan CRCN Hospital- N07°52'21.8" E009°47'18.6" and Angwan Sabon Kasuwa – N07°52'28.4" E009°47'25.2") in Gindin Dorowa..

Sample Collection

The water samples were collected from the selected sites into clean, transparent amber bottles by first rinsing the bottles with the water samples and were labeled properly. All the water samples were collected by early hours (between 7 a.m. and 9 a.m.) of the day in triplicate. Some physicochemical parameters, which include pH, temperature, total dissolved solids, and electrical conductivity, were determined at the point of collection and were later transferred into ice-pack and transferred later to the laboratory for an immediate analysis.

Bacteriological Analysis

Bacteriological analysis of the water samples involved standard microbiological methods according to the method described by Nicholas *et al.* (2022) for determination of total heterotrophic bacterial count, total coliform count and total faecal coliform count. One milliliter (1 mL) each of the borehole water samples was pipette into 9 mL of sterile physiological saline and thoroughly mixed by swirling. The mixtures were diluted decimally until appropriate dilution was obtained. The spread plate method was used in inoculating aliquot portion (0.1 mL) of appropriate dilution into a sterilized nutrient agar medium. Plates were incubated at 37 °C for 24 to 48 hours for heterotrophic bacteria and the colonies obtained after incubation were counted and expressed as colony forming units per milliliter of water (CFU/mL-1). The physiological characteristics of the colonies and their number on the culture plates were used as the basis for the counting, taking into consideration their dilution number. Counts were made from the plates containing 30-300 colonies. The isolates were aseptically sub-cultured into fresh nutrient agar after counting and incubated at a temperature of 37 °C for 24 hours to obtain pure cultures of the isolates.

Preliminary identification of isolates was based on colony morphology, including colony size, shape, colour, pigmentation, and elevation. Microscopic examination was carried out after Gram staining to differentiate Gram-positive and Gram-negative bacteria. Further identification was achieved using the following standard biochemical tests;

Catalase Test

Using sterile glass rod, suspected colonies were immersed in tube containing 2 ml of 3% hydrogen peroxide. Presence of bubbles indicates a positive result (Cheesbrough, 2009; Collee *et al.*, 2016).

Coagulase Test

1ml of human plasma were added to test tubes and a loopful of the bacteria isolates inoculated. The test tubes were incubated at 37°C for 1 hour in a water bath to observe for presence of clouding and clotting. Interpretation: A positive coagulase test is represented by any degree of solid clotting.

Indole Test: Isolated colonies were inoculated in peptone water, which contains amino acid tryptophan and incubated at 37°C for 24 hours. After incubation, kovac's reagent was added and the test tube was shaken gently. The test tube was allowed to stand for 2 minutes. Interpretation: Formation of a red or pink colored ring at the top of the test tube is a positive result. This indicates the presence of tryptophase enzymes

Methyl red (MR) Test: The isolated colonies were inoculated into glucose phosphate broth, which contains glucose and a of the medium was tested by the addition of 5 drops of methyl red reagent. Interpretation: Development of red color is a positive result. Gram Negative bacteria produce yellow color.

Citrate Utilization Test: Isolated bacterial colonies were picked with a sterile inoculating loop and inoculated into slants of Simmon's citrate agar and incubated 24 to 48 hrs at 37°C. Interpretation: If the organism has the ability to utilize citrate, the medium changes its color from green to blue. This means the organism can utilize citrate as a sole carbon source and the result indicate that it helps identify the organism.

Physicochemical Analysis

The following physicochemical properties of the water samples were determined following standard analytical procedures of APHA (1995).

pH Value

The pH was determined using the pH meter (PHS-3E, Labo Hub instrument). Buffer solutions of different pH were used to standardize the pH meter.

Colour and Turbidity

The colour of the water samples was determined using a colour analyzer (WR10QC, China). The turbidity was measured by the use of turbidity meter (BEP-TB100, Infitec); the meter contains a bottle in which the water samples were induced. The bottle was inserted into a cavity hole on the turbidity meter which was allowed to read for 30 seconds, there after the reading was recorded.

Electrical Conductivity

Electrical conductivity of the water samples was estimated by the use of a conductivity meter (INE-EC110B, mrc instrument). The conductivity meter was standardized with buffer solution and temperature of different samples before the steady readings were noted.

Temperature

The temperature of each water sample was determined through the use of a mercury-bulb thermometer by immersing the bulb vertically into the samples and allowing it to stand until a steady temperature was achieved.

Total Dissolved Solids (TDS)

An empty beaker was weighed, and 50 ml of the water sample was measured into it and filtered into another beaker. The filtrate was heated to dryness, cooled, and reweighed until a constant mass was obtained. The value of the mass was recorded using the expression $TDS = \frac{W1-W2}{V} \times 1000$ sample volume (ml)

Dissolved Oxygen (DO)

The dissolved oxygen content of the water samples was measured by using a waterproof meter according to standard method of APHA (1995).

Statistical Analysis

Data generated from the microbiological and physicochemical analyses were summarized using descriptive statistics. Differences among sampling locations and water sources were evaluated using one-way analysis of variance (ANOVA), while frequency of occurrence of bacterial isolates was expressed as percentages. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 31, and statistical significance was considered at $P < 0.05$.

RESULTS AND DISCUSSION

Results and Discussion

Table 1 presents the total viable counts (TVC) of bacteria in colony-forming units per milliliter (cfu/ml) for borehole samples collected from three areas in Gindin Dorowa. The results reveal high levels of microbial contamination across all samples. For borehole water, counts ranged from 2.0×10^6 cfu/ml in Angwan Sabon Kasuwa to 2.6×10^6 cfu/ml in Angwan CRCN Hospital. These values exceeded the Nigerian Standard for Drinking Water Quality of 100 cfu/ml. With the progression of time, certain physiochemical parameters could influence the accumulation of bacteria in the water samples, rendering them unfit for consumption. For instance, a rise in borehole temperature of 20–28°C can promote bacterial growth and proliferation (Adamu et al., 2024). Additionally, the total coliform rule according to WHO requires a maximum concentration of zero for total coliform, fecal coliform, and *E. coli* in drinking water (WHO, 2018). coliform, and fecal identification in the borehole water samples may be due to cross contamination from different sources, possible compromised well casings, poor construction, or direct ingress of contaminated surface water. The elevated counts in borehole water at Angwan CRCN Hospital may be linked to high human activity in the area (Viban et al., 2021). Water with total viable counts in the range of 10^6 cfu/ml is indicative of gross contamination and elevates the risk of waterborne diseases such as gastroenteritis, typhoid fever, and other bacterial infections (Tenebe et al., 2024).

Table 1: Total Viable Counts of Bacteria in Colony Forming Unit Per Milligram (Cfu/Ml) Of Borehole Water Samples from The Selected Areas in Gindin Dorowa

Sample location	Sample	Total counts in cfu/ml
Angwan Burofi	Borehole water	2.1×10^6
Angwan CRCN Hospital	Borehole water	2.6×10^6
Angwan Sabon Kasuwa	Borehole water	2.0×10^6

Table 2 presents the morphological characteristics and Gram reaction of bacteria isolated from water samples. The result reveals a clear dichotomy between Gram-positive and Gram-negative organisms based on their growth characteristics. *Bacillus subtilis* and *Staphylococcus aureus* are Gram-positive, and their absence of growth or a differential reaction on MacConkey agar aligns with the medium's selectivity for Gram-positive bacteria. Among the Gram-negative rods, a further distinction is made based on lactose fermentation. *Escherichia coli* is a lactose fermenter that produces moist, yellow colonies on MacConkey agar due to acid production (Saad, 2025). *Pseudomonas aeruginosa* and *Shigella spp.* are non-lactose fermenters, forming colorless or transparent

colonies (Sachdev, 2015). The presence of lactose-fermenting coliforms often suggests recent fecal contamination, while non-fermenters like *Pseudomonas* may indicate environmental contamination or opportunistic pathogens (Pereira et al., 2023).

Staphylococcus aureus is described as having small, moist, yellow colonies, a feature consistent with its ability to produce carotenoid pigments. *Bacillus subtilis* presents as small, moist, white or slightly yellow colonies, often with a characteristic ground-glass appearance. The description of *Pseudomonas aeruginosa* includes a blue-green color, which is indicative of its production of diffusible pigments such as pyocyanin, a key identifying feature (Abdelaziz et al., 2023).

Table 2: Morphological Characteristics of Isolated Bacteria and Their Gram Reaction

Bacteria	Morphology	Gram stain reaction
<i>Bacillus subtilis</i>	Small, moist, white or slightly yellow colonies	Gram-positive rod
<i>Escherichia coli</i>	Moderate, moist yellow lactose fermenter colonies	Gram-negative rod
<i>Pseudomonas aeruginosa</i>	Moderate, moist, blue-green, non-lactose fermenter colonies	Gram-negative rod
<i>Shigella spp</i>	Small, moist, colourless/transparent, non-lactose fermenter colonies	Gram-negative rod
<i>Staphylococcus aureus</i>	Small, moist, yellow lactose, fermenter colonies	Gram-positive cocci

The biochemical characterization outlined in Table 3 was instrumental in confirming the presumptive identification of the bacterial isolates derived from the water samples. Among the Gram-positive bacteria, *Staphylococcus aureus* was identified by its positive catalase and coagulase reactions, the latter being a key virulence factor that distinguishes it from other coagulase-negative staphylococci (França et al., 2021).

In contrast, *Bacillus subtilis*, while also catalase-positive, tested negative for coagulase and exhibited a unique profile of citrate utilization without the production of indole or a positive methyl red reaction, consistent with its saprophytic nature. These enzymatic profiles not only validated the Gram stain observations but also highlighted the metabolic diversity between these two Gram-positive genera.

For the Gram-negative isolates, the biochemical test battery effectively differentiated the enteric bacteria from non-fermenters. *Escherichia coli* was identified by its classic pattern of being indole-positive, methyl red-positive, and citrate-negative, which is consistent with its role as a fecal indicator bacterium (Caramujo *et al.*, 2026). *Shigella spp.*, while sharing the methyl red-positive trait, was distinguished from *E. coli* by its negative indole reaction, confirming its identity as a non-motile, non-lactose fermenting pathogen. The presence of these bacteria in the water samples is particularly significant as they are directly associated with fecal contamination and pose serious gastrointestinal health risks (Khan and Gupta, 2020).

Pseudomonas aeruginosa stood out with a distinctly different biochemical fingerprint, being oxidase-positive and citrate-positive while negative for indole and methyl red. The positive oxidase test is a hallmark of this non-fermentative, aerobic rod. The ability of *Pseudomonas* to thrive in diverse environments, coupled with its resistance to many antimicrobial agents, makes its prevalence in well and borehole water, a major public health concern (Serwecińska, 2020). Obuekwe *et al.* (2021) reported the presence of four (4) Gram positive bacteria; *Bacillus cereus*, *Staphylococcus aureus*, *Micrococcus sp.* and *Bacillus subtilis* and three (3) Gram negative bacteria; *Shigella sp.*, *Salmonella sp.* and *E. coli*.

Table 3: Biochemical Reactions of Bacteria Isolated from Borehole Water Samples from Different Locations in Gindin Dorowa

Bacteria	Catalase test	Coagulase test	Indole test	Methyl red test	Citrate test	Oxidase test	Gram reaction
<i>Bacillus subtilis</i>	+	-	-	-	+	-	+Rod
<i>Escherichia coli</i>	+	-	+	+	-	-	-Rod
<i>Pseudomonas aeruginosa</i>	+	-	-	-	+	+	-Rod
<i>Shigella spp</i>	+	-	-	+	-	-	-Rod
<i>Staphylococcus aureus</i>	+	+	-	+	+	-	+Cocci

Table 4: The borehole water samples from all three locations were recorded as colourless. Color is an important physical quality of water that affects the acceptability of water by consumers, while turbidity usually results from the presence of colloidal materials such as clay, silt, and finely divided organic matter in water samples, which provide adsorption sites for chemicals that may be harmful to health or cause undesirable tastes or odors (Obuekwe *et al.*, 2021).

Borehole water samples exhibited turbidity values of 55.9 NTU (Angwan Burofi), 55.6 NTU (Angwan CRCN Hospital), and 40.3 NTU (Angwan Sabon Kasuwa). All recorded values far exceeded the WHO (2017) and SON standard of 5 NTU, indicating severe particulate contamination. The findings of the present study deviate from Obunadike and Akerele (2023) that reported turbidity of 0 to 13.71°C for borehole water from Lekki, Lagos, Nigeria. Garba *et al.* (2018) reported no turbidity for borehole water in Dutse Metropolitan Jigawa State, Nigeria. High turbidity water is often unacceptable to consumers due to its appearance, and more importantly, it compromises disinfection processes (Zimoch and Paciej, 2020). The turbidity which was above the WHO permissible level in the borehole water sample, is an indication of the presence of colloidal solids in the water sample and could translate that the water is unsafe for consumption. Higher turbidity level is associated with higher risk of developing gastrointestinal diseases (Obuekwe *et al.*, 2021).

pH values ranged from 6.1 to 6.7, with only Angwan CRCN Hospital (6.7) falling within the WHO (2017) and SON recommended range of 6.5–8.5. Angwan Burofi (6.3) and Angwan Sabon Kasuwa (6.1) were slightly acidic. This result is similar to the findings by Garba *et al.* (2018) that reported pH of 6.5 to 7.5 for borehole water in Dutse Metropolitan Jigawa State, Nigeria. Obunadike and Akerele (2023) reported pH of 6.8 to 7.5 for borehole water from Lekki, Lagos, Nigeria. Atuanya *et al.* (2018) similarly reported pH values of 5.6 – 6.6 in stored borehole water in Benin City. Acidic conditions can reduce the efficacy of chlorine-based disinfection, which is particularly concerning given the high bacterial counts documented earlier (Clayton *et al.*, 2021).

Temperatures were recorded at 30.3°C (Angwan Burofi), 30.1°C (Angwan CRCN Hospital), and 25.0°C (Angwan Sabon Kasuwa). The WHO (2017) guideline suggests an ambient temperature range, typically around 29°C for tropical climates. Garba *et al.* (2018) reported temperature of 29.5 to 30.4°C for borehole water in Dutse Metropolitan Jigawa State, Nigeria. Obunadike and Akerele (2023) reported temperature of 27 to 29°C for borehole water from Lekki, Lagos, Nigeria. The elevated temperatures observed reflect the tropical climate of Gindin Dorowa and the relatively shallow depths of these water sources, which allow for greater influence of atmospheric conditions.

DO concentrations were 7.9 mg/L (Angwan Burofi), 8.3 mg/L (Angwan CRCN Hospital), and 7.0 mg/L (Angwan Sabon Kasuwa). All values fell within or above the WHO (2017) and SON recommended range of 6.5–8.0 mg/L. Adequate dissolved oxygen levels indicate that the water sources are not overloaded with organic pollutants that would otherwise deplete oxygen through microbial decomposition (Singh *et al.*, 2021).

Conductivity values were 37.3 S/m (Angwan Burofi), 19.6 S/m (Angwan CRCN Hospital), and 30.1 S/m (Angwan Sabon Kasuwa). All values remained well below the WHO (2017) guideline of 1000 S/m and the SON standard of 1500 S/m, indicating that the water is not excessively mineralized and is acceptable from a salinity perspective. Garba *et al.* (2018) reported conductivity of 214.2 to 628.5 us/cm for borehole water in Dutse Metropolitan Jigawa State, Nigeria. Obunadike and Akerele (2023) reported conductivity of 202 to 1390 us/cm for borehole water from Lekki, Lagos, Nigeria. The relatively low conductivity across all samples indicates that the water does not contain excessive salts that would cause taste issues or gastrointestinal disturbances (Dietrich and Devesa, 2019).

Borehole water samples had TDS values of 439.0 mg/L (Angwan Burofi), 474.1 mg/L (Angwan CRCN Hospital), and 428.6 mg/L (Angwan Sabon Kasuwa). All values were within the WHO (2017) and SON acceptable limit of 500 mg/L, indicating that the water is not excessively mineralized. The findings by Eneje and Ogoko, (2025) also reported that

the values of total dissolved solids (TDS) in most of the borehole water samples at Karu Municipal, Nasarawa state were within the recommended permissible limit of 1000 mg/L (WHO, 2011). Water with very low levels of total dissolved solids tend to exhibit characteristic taste while higher levels of total dissolved solids impact unpleasant mineral taste and

causes excessive scaling in electric boilers, heaters and water pipes. of 96.4 to 899 mg/L for borehole water from Lekki, Lagos, Nigeria. Elevated TDS can affect taste acceptability and may contribute to scaling in pipes and appliances (Dietrich and Devesa, 2019).

Table 4: Physicochemical Analysis of Borehole Water Samples from The Three Selected Areas in Gindin Dorowa

Parameters	Angwan Burofi	Angwan CRCN Hospital	Angwan Sabon Kasuwa	WHO	SON
Color	Colorless	Colorless	Colorless	Colorless	Colorless
pH	6.3	6.7	6.1	6.5-8.5	6.5-8.5
Temperature	30.3°C	30.1°C	25.0°C	29°C	Ambient
Turbidity NTU	55.9	55.6	40.3	5	5
Dissolved Oxygen Mg/l	7.9	8.3	7.0	6.5-8	6.5-8
Conductivity S/m	37.3	19.6	30.1	1000	1500
Total dissolved solids Mg/l	439.0	474.1	428.6	500	500
Mean	96.1	99.1	89.5		
Std. Dev	169.0	184.6	166.7		
C.V	175.8	186.3	186.2		
P.value	< 0.026				

CONCLUSION

This study revealed that the borehole water in selected locations at Gindin Dorowa are severely contaminated and unfit for human consumption. The water samples exhibited total viable counts exceeding 10^6 cfu/ml, far above WHO and SON permissible limits. The microbiological analysis confirmed the presence of pathogenic organisms, including *Escherichia coli*, *Shigella spp.*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*, indicating a dual threat of fecal contamination and opportunistic pathogens, suggesting compromised structural integrity. The water quality deteriorated, with turbidity values exceeding standards and pH levels falling below the recommended range, creating conditions conducive to corrosion and microbial survival.

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