FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 11, June, 2026, pp 189 – 194
DOI: https://doi.org/10.33003/fjs-2026-1011-5279

Evaluation of Levels of Some Physicochemical and Bacteriological Parameters in Water from Selected Boreholes in Northern Senatorial Zone of Taraba State, Nigeria

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ABSTRACT
This study evaluated the levels of some physicochemical and bacteriological parameters of water from selected boreholes in the Northern Senatorial Zone of Taraba State, Nigeria. Water samples were analysed using standard laboratory procedures. Physicochemical parameters analyzed included pH, temperature, electrical conductivity, turbidity, total dissolved solids (TDS), alkalinity, hardness, major ions, disinfectant residues, and selected heavy metals, while bacteriological quality was evaluated using total coliforms, *Escherichia coli*, *Salmonella–Shigella*, *Bacillus subtilis*, and total heterotrophic bacterial counts. Overall water quality was assessed using the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI). The results showed that pH values ranged from 6.4 - 7.8, remaining within the recommended limits of the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality. Electrical conductivity varied between 180 and 920 µS/cm, while total dissolved solids ranged from 110 - 680 mg/L, with some locations exceeding permissible limits. Turbidity values ranged from 0.4 - 6.2 NTU, and total hardness ranged from 42 - 286 mg/L. Metals such as chromium, cadmium, nickel, manganese, and cobalt were generally detected at concentrations within the permissible limits of WHO, though higher values of nickel and cadmium were observed in some boreholes. Total coliform counts ranged from 24 - 210 cfu/100 mL, *E. coli* ranged from 6 - 38 cfu/100 mL, *Salmonella–Shigella* ranged from 0 - 120 cfu/100 mL, and total heterotrophic bacterial counts ranged from 39 - 240 cfu/100 mL, all exceeding recommended guideline limits for potable water. The CCME-WQI values ranged from 36.95 – 41.01%, classifying borehole water quality as poor. There is need for treatments, regular water quality monitoring, improved borehole sanitation, and appropriate household water treatment practices.

Received: 22 Jan. 2026
Accepted: 12 Feb. 2026
Published: 14 July 2026

Keywords: Borehole Water, Physicochemical Parameters, Bacteriological Quality, CCME-WQI, Taraba State

INTRODUCTION

Access to safe and potable water is essential for human health, economic development, and environmental sustainability. Safe drinking water reduces the incidence of waterborne diseases and contributes significantly to improved quality of life and productivity (WHO, 2018; UNICEF & WHO, 2021). Groundwater, particularly from boreholes, serves as a major source of domestic water supply in many parts of Nigeria due to its perceived purity, reliability, and relative protection from surface contamination. Groundwater is water found beneath the Earth's surface in the pores and fractures of soil and rock formation known as aquifers. However, increasing population pressure, rapid urbanization, agricultural intensification, and poor waste management practices have raised serious concerns about the quality of groundwater resources, even in areas traditionally considered safe (Bain *et al.*, 2025). In many developing regions, groundwater contamination has become a silent public health threat due to the absence of routine monitoring and inadequate regulation of water sources (Edokpayi *et al.*, 2018). In Nigeria, inadequate provision of treated pipe-borne water has compelled many households to depend heavily on domestic boreholes for drinking, cooking, and other household purposes. Although borehole water is often regarded as safer than surface water and hand-dug wells, several studies have shown that groundwater quality can be compromised by both geogenic processes and anthropogenic activities such as indiscriminate waste disposal, excessive use of agrochemicals, seepage from septic tanks, industrial effluents, and improper borehole construction (Edokpayi *et al*., 2018). Several studies across Nigeria have reported bacteriological contamination of borehole water, often attributed to poor sanitation, leaking septic tanks, and inadequate borehole protection (Arya *et al.*, 2025).

The quality of borehole water is commonly evaluated using physicochemical and bacteriological parameters. Physicochemical characteristics such as pH, electrical conductivity, total dissolved solids, turbidity, hardness, alkalinity, major ions, disinfectant residuals, and trace metals influence water palatability, corrosiveness, and potential toxicity (APHA, 2018; WHO, 2018). The abnormal levels of these parameters affect water palatability, corrosiveness, and toxicity, and may also enhance the mobility of heavy metals in groundwater systems (Alao *et al.*, 2024). Elevated concentrations of dissolved solids, nutrients, and heavy metals may pose long-term health risks, while extreme pH

values can enhance the solubility and mobility of toxic metals in groundwater systems (Edokpayi *et al*., 2018). In addition to chemical characteristics, bacteriological quality is a critical indicator of water safety. The presence of pathogenic microorganisms, particularly total coliforms and *Escherichia coli*, indicates fecal contamination and increases the risk of waterborne diseases such as diarrhea, typhoid fever, cholera, and dysentery (WHO, 2018; Bain *et al*., 2025). Boreholes located close to septic tanks, refuse dumps, agricultural fields, and poorly drained areas are especially vulnerable to microbial contamination, despite their depth. The Northern Senatorial Zone of Taraba State comprises predominantly rural and semi-urban communities where domestic boreholes constitute a major source of drinking water. Despite the widespread reliance on borehole water in this region, comprehensive data on its physicochemical and bacteriological quality remain limited. This lack of information poses challenges to effective water resource management, regulatory enforcement, and public health protection (Edokpayi *et al*., 2018).
This study therefore aims to assess the physicochemical and bacteriological quality of water from selected domestic boreholes in the Northern Senatorial Zone of Taraba State, Nigeria. The results are compared with the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines to evaluate water suitability for domestic use and to provide baseline data for groundwater quality monitoring and sustainable water management in the area.

MATERIALS AND METHODS

Study Area

This study was conducted in the Northern Senatorial Zone of Taraba State, Nigeria, comprising selected Local Government Areas (LGAs) where domestic boreholes serve as major sources of drinking and household water. The area lies within the Guinea Savannah ecological zone and experiences distinct wet and dry seasons, with relatively high temperatures throughout the year (Taraba State Ministry of Environment, 2019). Owing to limited access to treated pipe-borne water, residents across the LGAs rely predominantly on borehole water for domestic use (Sulaiman *et al.,* 2025). Figure 2.1 below shows the study area map.

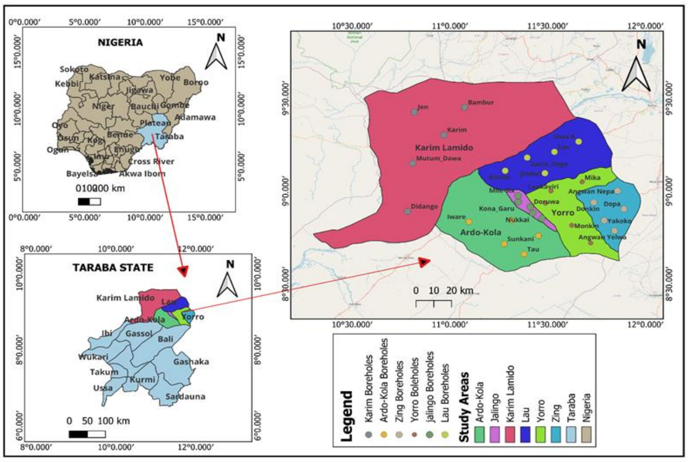

Figure 1: Study Area Map

Sample Collection

Water samples were collected from selected domestic boreholes in each Local Government Area within the Northern Senatorial Zone of Taraba State. Boreholes were selected based on frequency of use, accessibility, and proximity to residential areas, in line with previous groundwater quality studies in Nigeria (Odu *et al.,* 2020).
Samples for physicochemical and chemical analyses were collected in clean 1.5 L high-density polyethylene bottles, while samples for microbiological analysis were collected in sterile 500 mL glass bottles. Prior to collection, all sample containers were thoroughly washed with detergent, rinsed with distilled water, and finally rinsed three times with the borehole water to be sampled (APHA, 2018).

Methodology: Physicochemical and Bacteriological Analysis

Physicochemical parameters were determined using standard procedures recommended by the American Public Health Association (APHA, 2018, Yusuf *et al.,* 2024). Bacteriological Analyses were carried membrane and pour plates methods (Popoola **et al., (***2019*).

RESULTS AND DISCUSSION

Results

Table 1. Result of Analysis of Physicochemical Parameters for Water from the Study Areas

S/N	Parameter	Jalingo	Ardo-Kola	Lau	Yorro	Zing	Karim Lamido	Standard WHO, 2018, NSDWQ
1.	pH	7.30±0.00	6.96±0.00	7.34±0.00	6.85±0.00	7.45±0.00	6.68±0.00	6.5 – 8.5
2.	E. conductivity (μS/cm)	514.00±0.0	655.00±0.00	497.00±0.00	486.00±0.00	841.00±0.00	780.00±0.00	1000
3.	Colour (ptCo)	0.00±0.00	6.00±0.00	0.00±0.00	14.00±0.00	0.00±0.00	16.00±0.00	15
4.	Temperature (oC)	32.40±0.00	32.60±0.00	32.10±0.00	32.20±0.00	32.30±0.00	33.30±0.00	Ambient
5.	Alkalinity (mg/L)	30.00±0.00	45.00±0.00	60.00±0.00	80.00±0.00	50.00±0.00	50.00±0.00	200

S/N	Parameter	Jalingo	Ardo-Kola	Lau	Yorro	Zing	Karim Lamido	Standard WHO, 2018, NSDWQ
6.	Total hardness (mg/L)	80.00±0.00	80.00±0.00	45.00±0.00	85.00±0.00	85.00±0.00	70.00±0.00	120
7.	Turbidity (mg/L)	2.28±0.00	2.28±0.00	4.84±0.00	6.15±0.00	0.660±0.00	7.77±0.00	5
8.	Total dissolved solids (mg/L)	411.20±0.00	524.00±0.00	397.60±0.00	388.80±0.00	672.80±0.00	624.00±0.00	500
9.	Salinity (mg/L)	282.70±0.00	360.25±0.00	273.35±0.00	267.30±0.00	462.55±0.00	429.00±0.00	500
10.	Total chlorine (mg/L)	0.14±0.00	0.14±0.00	0.22±0.00	0.17±0.00	0.21±0.00	0.17±0.00	4
11.	Chlorinedioxide (mg/L)	0.56±0.00	0.48±0.00	0.70±0.00	0.32±0.00	0.53±0.00	0.36±0.00	0.05
12.	Ozone (mg/L)	0.18±0.00	0.23±0.00	0.18±0.00	0.18±0.00	0.19±0.00	0.30±0.00	1.2
13.	Chloride (mg/L)	156.48±0.00	199.40±0.00	151.30±0.00	147.77±0.00	256.02	237.45±0.00	250
14.	Residual chlorine (mg/L)	0.12±0.00	0.13±0.00	0.11±0.00	0.09±0.00	0.14±0.00	0.11±0.00	0.2
15.	Free chlorine (mg/L)	0.02±0.00	0.01±0.00	0.11±0.00	0.08±0.00	0.07±0.00	0.06±0.00	5
16.	Sulphide (mg/L)	0.00±0.00	0.01±0.00	0.01±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.05
17.	Nitrate (mg/L)	4.84±0.00	2.75±0.00	2.83±0.00	2.12±0.00	3.99±0.00	6.26±0.00	50
18.	Cyanide (mg/L)	0.00±0.00	0.00±0.00	0.01±0.00	0.01±0.00	0.00±0.00	0.00±0.00	0.07
19.	Aniline (mg/L)	0.10±0.00	0.64±0.00	0.00±0.00	0.24±0.00	0.00±0.00	0.50±0.00	4
20.	Urea (mg/L)	0.00±0.00	0.00±0.00	0.02±0.00	0.00±0.00	0.24±0.00	0.05±0.00	0
21.	Phenol (mg/L)	0.07±0.00	0.24±0.00	0.13±0.00	0.02±0.00	0.00±0.00	0.11±0.00	0.1
22.	Chromium (mg/L)	0.02±0.00	0.00±0.00	0.00±0.00	0.02±0.00	0.00±0.00	0.19±0.00	0.05
23.	Cadmium (mg/L)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.02±0.00	0.05±0.00	0.005
24.	Nickel (mg/L)	0.00±0.00	1.82±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.02
25.	Manganese (mg/L)	0.00±0.00	0.00±0.00	0.09±0.00	0.23±0.00	0.00±0.00	0.26±0.00	3
26.	Cobalt (mg/L)	0.0176±0.00	0.0106±0.00	0.0106±0.00	0.0070±0.00	0.0176±0.00	0.0070±0.00	0.1

Discussion

The borehole water pH values ranged from 6.68 - 7.45, with a mean of 7.10, all within the WHO and NSDWQ acceptable range of 6.5-8.5 (WHO, 2018; NSDWQ, 2015). Similar neutral pH values have been reported in groundwater studies in northeastern Nigeria, reflecting natural geochemical equilibrium. Kayode *et al.,* (2024) also reported comparable pH levels in borehole water from the Niger Delta region. Also observed that groundwater in many tropical environments typically exhibits slightly acidic to neutral pH due to natural geochemical processes.

Water temperatures between 32.10°C and 33.30°C reflect the typical thermal regime of shallow aquifers in tropical climates, and are comparable to reports elsewhere in the Savannah zone of Nigeria (Edokpayi *et al*., 2018). Elevated temperature may increase microbial activity and influence chemical reaction rates in water (APHA, 2018).

Electrical conductivity (EC) values across all sampling points (486–841 µS/cm) remained below the WHO maximum guideline of 1000 µS/cm (WHO, 2018), indicating moderate ion content in the borehole water.

Total dissolved solids (TDS) values ranged from 388.80 mg/L (Yorro) to 672.80 mg/L (Zing). While most locations were below the NSDWQ limit of 500 mg/L, boreholes in Zing, Ardo-Kola, and Karim-Lamido exceeded this limit, indicating elevated mineralization. High TDS levels often signal aquifer influence by mineral dissolution or anthropogenic contamination (Popoola*et al.,* 2019). Similar exceedances have been observed in groundwater studies in southwestern Nigeria (Popoola *et al.,* 2019) and in urban boreholes in Makurdi, Nigeria (Ndimbo*et al.,* 2022). Salinity ranged from 267.30–462.55 mg/L, below WHO's recommendation that fresh drinking water should have low salinity (WHO, 2018). However, elevated salinity in Zing and Karim-Lamido suggests mineral contributions from geological formations or infiltrating dissolved salts.

Turbidity values at Yorro (6.20 mg/L) and Karim-Lamido (7.77 mg/L) exceeded the WHO and NSDWQ recommended value of ≤ 5 mg/L (WHO, 2018; NSDWQ, 2015). High turbidity levels reduce aesthetic quality and may shield microorganisms from disinfection, posing health treatment challenges (APHA, 2018).

Colour exceeded the WHO limit of 15 Pt-Co units at Karim-Lamido. Elevated colour often indicates dissolved organic matter, iron, or trace metals — a trend reported in other Nigerian groundwater studies (Edokpayi *et al*., 2018). Such characteristics may be linked to inadequate aquifer protection near waste deposits. Alkalinity values (30–80 mg/L) were below WHO's recommended limit of ≤200 mg/L (WHO, 2018), indicating low buffering capacity. Water with low alkalinity can be more susceptible to pH fluctuations.

Total hardness (45–85 mg/L) classified the borehole water as soft to moderately hard, posing no immediate risk to human health or household appliances. Comparable hardness levels have been reported in borehole studies in Taraba and other northern states (Akoteyon*et al.,* 2011), reflecting dominance of calcium and magnesium in aquifer geochemistry.

Chloride concentrations ranged from 147.77 mg/L to 256.02 mg/L. Only water from Zing slightly exceeded the WHO limit of ≤250 mg/L (WHO, 2018), suggesting potential saline intrusions or sewage impacts. Reported water quality studies in northern Nigeria have also noted elevated chloride in densely populated zones.

Total chlorine, free chlorine, and residual chlorine values were low across all sites, indicating limited disinfection expected in groundwater that is typically not chlorinated before consumption. However, absence of adequate disinfectant residual can increase vulnerability to microbial contamination (WHO, 2018).

Nitrate levels at all locations were well below WHO's limit of ≤50 mg/L, suggesting minimal influence of agricultural runoff or septic leachate, consistent with findings of (Adeyinka *et al*., 2021). Cyanide was detected at low concentrations, below WHO's guideline of ≤0.07 mg/L (WHO, 2018). Low cyanide levels indicate limited industrial pollution influence, but continued monitoring is recommended due to its acute toxicity. Sulphide, aniline, urea, and phenol were generally low, except for slightly elevated phenol in Karim-Lamido. Phenolic compounds are associated with industrial effluent and degradation of organic matter, and have been observed in contaminated groundwater elsewhere (Edokpayi *et al*., 2018).

Chromium and cadmium were generally within permissible limits (WHO, 2018) except for cadmium at Zing and Karim-Lamido, which was elevated. Cadmium is a non-essential metal with known carcinogenic and kidney toxicity risks (Popoola *et al.,* 2019). Similar trace metal concerns have been reported in groundwater studies in southwestern Nigeria (Popoola *et al.,* 2019), emphasizing the need for regular heavy metal monitoring.

Nickel exceeded the WHO limit of 0.02 mg/L at Ardo-Kola (1.82 mg/L), indicating significant anthropogenic influence, possibly from agricultural chemicals, industrial sources, or corroded infrastructure. Elevated nickel in boreholes has been documented in other Nigerian sub-regions, underscoring its emerging water quality concern (Ndimbo *et al.,* 2022).

Bacteriological Quality

Bacteriological analysis of borehole water samples from the Northern Senatorial Zone of Taraba State revealed widespread microbial contamination across all sampled Local Government Areas (LGAs) (Table 3.2).

Table 2: Result of Analysis of Bacteriological Parameters of Borehole Water obtained from Northern Senatorial Zone, Taraba State

S/N	Parameter	Jalingo	Ardo – Kola	Lau	Yorro	Karim-Lamido	Zing	W.H.O. Standard, 2018; NSDWQ
1.	Total coliform (cfu/100 mL)	60	23	19	90	20	20	10
2.	E. coli (cfu/100 mL)	30	15	11	60	10	18	0
3.	Salmonella shigella (cfu/100 mL)	0	4	7	1	6	4	0
4.	Bacillus subtilis (cfu/100 mL)	0	7	0	3	4	2	0
5.	Total Heterotrophic count (cfu/100 mL)	92	48	25	100	30	29	15

Total coliform counts ranged from 19 cfu/100 mL in Lau to 90 cfu/100 mL in Ardo-Kola, exceeding the WHO and NSDWQ permissible limit of ≤10 cfu/100 mL in all locations (WHO, 2018; NSDWQ, 2015). The consistently high coliform counts indicate significant microbial pollution and poor sanitary protection of boreholes in the study area. *Escherichia coli* was detected in all borehole water samples, with counts ranging from 10 cfu/100 mL in Lau to 60 cfu/100 mL in Ardo-Kola, contrary to the WHO guideline which requires complete absence (0 cfu/100 mL) in drinking water. The presence of *E. coli* is a direct indicator of fecal contamination and suggests infiltration from septic tanks, pit latrines, or surface runoff into groundwater systems. This finding poses a serious public health risk, as *E. coli* contamination is associated with outbreaks of diarrheal diseases, typhoid fever, and other gastrointestinal infections (Bain *et al*., 2025).

Counts of Salmonella–Shigella ranged from 15 - 55 cfu/100 mL, while Bacillus subtilis ranged from 12 - 40 cfu/100 mL across the LGAs. Their presence further confirms the microbiological unsuitability of the borehole water for direct human consumption. These organisms are commonly linked to fecal contamination and poor hygiene conditions (Hanson *et al.,* 2023).

Total heterotrophic bacterial counts varied between 25 cfu/100 mL (Lau) and 100 cfu/100 mL (Ardo-Kola), exceeding the WHO recommended limit of ≤15 cfu/100 mL for potable water. Elevated heterotrophic counts indicate high organic matter availability and favourable conditions for bacterial proliferation, which may compromise the effectiveness of household water treatment methods.

The bacteriological results clearly demonstrate that none of the borehole water samples met WHO or NSDWQ microbiological standards for drinking water. These findings contradict the common perception that borehole water is inherently safe due to depth and natural filtration. Similar studies in Nigeria and other parts of sub-Saharan Africa have reported high microbial loads in borehole water, particularly where boreholes are poorly constructed or located close to septic systems and refuse dumps (Hanson *et al.,* 2023).

The widespread detection of coliforms, *E. coli*, and pathogenic bacteria underscores the urgent need for improved borehole siting, sanitary protection, regular monitoring, and appropriate household or community-level water treatment before consumption.

Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI)

The suitability of borehole water in the study area was evaluated using the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI), which integrates multiple physicochemical and microbiological parameters into a single numerical score that reflects overall water quality status (CCME, 2017). The CCME-WQI is widely applied in groundwater quality assessments because it provides a comprehensive and easily interpretable framework for decision-making by scientists, water managers, and policymakers (Hanson *et al.,* 2023). Table 3.3 shows water quality index values in Northern Senatorial Zone of Taraba State.

Table 3: Result of Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) Statistical Analysis of Physicochemical and Bacteriological Parameters of Borehole Water Obtained from Northern Senatorial Zone Taraba State

S/N	Sampling site	Scope (F1)	Frequency (F2)	Amplitude (F3)	CCME WQI (%)	Rating
1.	Jalingo	14.81481481	14.81481481	99,99100139	41,01	Poor
2.	Ardo-Kola	27.5862069	27.5862069	99.98885134	38.03	Poor
3.	Lau	23.07692308	23.07692308	99.99000096	39.22	Poor
4.	Yorro	24.13793103	24.13793103	99.99546913	38.99	Poor
5.	Zing	27.5862069	27.5862069	99.98791824	38.03	Poor
6.	Karim-Lamido	31.03448276	31.03448276	99.99369619	36.95	Poor

The computed CCME-WQI values for the borehole water samples ranged from 36.95-41.0%, indicating spatial variation in groundwater quality across the Northern Senatorial Zone of Taraba State. Borehole water from Jalingo (41.0%) and Lau was classified as poor, suggesting that water quality generally failed to meet the WHO and NSDWQ guidelines. According to CCME classification, water in this category is protected with high impairment and is usually unsuitable for domestic use. Therefore, periodic monitoring is required (CCME, 2017). The relatively low WQI scores reflect higher microbial loads and exceedances of physicochemical limits.

In contrast, borehole water from Jalingo, Yorro, Zing, Ardo-Kola, Lau and Karim-Lamido was classified as poor, indicating that water quality ishighly impaired due to frequent exceedances of guideline limits. This classification suggests that the water may not be suitable for domestic use and requires treatment, particularly because of elevated turbidity, total dissolved solids, heavy metals, and bacteriological contamination observed in these locations. Similar "poor" WQI classifications have been reported for borehole water in urban and semi-urban areas of Nigeria, where increased population density and inadequate sanitation infrastructure contribute to groundwater contamination (Hanson *et al.,* 2023).

The CCME-WQI results demonstrate that variations in borehole water quality across the study area are largely controlled by both physicochemical and microbiological parameters. Turbidity, TDS, heavy metals, total coliforms, and *Escherichia coli* were the dominant contributors to WQI deterioration. The observed pattern aligns with findings from other Nigerian groundwater studies that applied the CCME-WQI and reported increased vulnerability of shallow or poorly protected boreholes to contamination from anthropogenic activities (Laniyan & Adewumi, 2019).

The CCME-WQI assessment therefore provides a summary of groundwater quality conditions in the Northern Senatorial Zone of Taraba State and highlights the urgent need for improved borehole construction standards, sanitary protection, regular water quality monitoring, and appropriate water treatment.

Public Health Implications

Although many chemical parameters remained within guideline limits, widespread microbial contamination and occasional physicochemical exceedances pose serious public health risks. Consumption of such water without treatment may lead to diarrheal diseases, metal toxicity, and chronic health effects (Bain *et al*., 2025; WHO, 2018).

The elevated nickel and cadmium and frequent coliform detection highlight the need for sanitation improvements, protective borehole design, and regular water quality monitoring.

CONCLUSION

This study assessed the physicochemical, bacteriological, and water quality of selected domestic boreholes in the Northern Senatorial Zone of Taraba State, Nigeria, using standard analytical methods and the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI). The findings provide important insights into the suitability of groundwater sources widely relied upon for domestic use in the study area.

The physicochemical analysis revealed that most parameters, including pH, electrical conductivity, alkalinity, hardness, nitrate, and salinity, were within the guideline limits prescribed by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ). However, elevated levels of total dissolved solids (TDS), turbidity, chloride, and certain heavy metals particularly nickel and cadmium were observed in some locations, indicating localized deterioration of groundwater quality likely linked to geogenic processes and anthropogenic activities.

Bacteriological analysis showed widespread microbial contamination across all sampled boreholes. Total coliforms and *Escherichia coli* were detected in all samples at concentrations exceeding WHO and NSDWQ permissible limits, while the presence of *Salmonella–Shigella*, *Bacillus subtilis*, and high total heterotrophic bacterial counts further confirmed the microbiological unsuitability of the borehole water for direct consumption. These results demonstrate that, despite acceptable physicochemical characteristics in many cases, the borehole water poses significant public health risks due to fecal contamination and poor sanitary protection.

The CCME-WQI assessment integrated all measured parameters into a single index and revealed spatial variation in water quality. Borehole water from Jalingo, Yorro, Zing, Ardo-Kola, Lau and Karim-Lamidowere rated as poor, reflecting frequent guideline exceedances and requires treatment before use. These highlight the combined influence of physicochemical exceedances and bacteriological contamination on groundwater quality in the study area.

The study concludes that most borehole water sources in the Northern Senatorial Zone of Taraba State are not microbiologically safe for drinking without treatment, despite meeting some physicochemical standards. Continuous reliance on untreated borehole water in the area poses potential short- and long-term health risks to the population. Borehole water in the study areas should be adequately treated before use, particularly through boiling, chlorination, or filtration, to eliminate pathogenic microorganisms and reduce health risks.

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