FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 12, June, 2026, pp 333 – 338
DOI: https://doi.org/10.33003/fjs-2026-1012-5270

Assessment of the Physicochemical and Bacteriological Quality of Borehole Water from Selected Locations in the Central Senatorial Zone of Taraba State, Nigeria

***[1]Jecancy Jesse Abaflous, [1]Ernest Isaac [2]Medjor Eunice Adebowale and [1]Medjor Weltime Odeguonor**

[1]Department of Chemical Sciences, Taraba State University, Jalingo, Taraba State, Nigeria
[2]Department of Civil Engineering, Taraba State University, Jalingo, Taraba State, Nigeria

*Corresponding authors' email: abaflousjecancy@gmail.com Phone No.: +234 8033632222

ABSTRACT
This study assessed the physicochemical and bacteriological quality of borehole water in five Local Government Areas (Bali, Gashaka, Gassol, Kurmi and Sardauna) within the Central Senatorial Zone of Taraba State, Nigeria. Twenty-five domestic boreholes were randomly selected, with one composite sample collected from each borehole and analysed using standard laboratory procedures (APHA, 2017). Physicochemical properties were determined using spectrophotometric, titrimetric and electrometric methods, while heavy metals were analysed by Atomic Absorption Spectrophotometry. Bacteriological quality was evaluated using membrane filtration and pour plate techniques. Most physicochemical parameters, including pH, electrical conductivity, and turbidity, total dissolved solids, chloride and nitrate, complied with World Health Organization (WHO) drinking water standards. However, phenol, cyanide, chromium, cadmium and nickel exceeded permissible limits in some locations, with Sardauna recording the highest concentrations for most contaminants. Bacteriological analysis revealed that total coliforms, *Escherichia coli*, *Salmonella–Shigella* and total heterotrophic bacteria were detected in all samples at levels exceeding the WHO guideline of zero colony-forming units per 100 mL, indicating widespread faecal contamination. Water quality assessment using the Canadian Council of Ministers of the Environment Water Quality Index classified all study locations as having poor water quality. The study concludes that borehole water across the study area is unsuitable for direct human consumption. It recommends routine water quality monitoring, improved wellhead protection, effective disinfection and household water treatment to reduce chemical and microbial health risks and ensure safe drinking water.

Received: 15th June 2026

Accepted: 17th July 2026

Published: 15th August 2026

Keywords: Borehole water; physicochemical parameters; bacteriological parameters; heavy metals; CCME Water Quality Index; Taraba State

INTRODUCTION

Water is an indispensable natural resource required for human survival, economic development, and environmental sustainability. Access to safe drinking water remains a major challenge in many developing countries, particularly in sub-Saharan Africa, where waterborne diseases continue to pose serious public health concerns. Contaminated drinking water has been linked to outbreaks of diseases such as cholera, dysentery, typhoid fever, and diarrhoea, which disproportionately affect vulnerable populations (WHO, 2017).

In Nigeria, the demand for potable water far exceeds the supply provided by public water utilities. Rapid population growth, urbanisation, and poor maintenance of water infrastructure have resulted in widespread dependence on alternative water sources such as boreholes, hand-dug wells, and surface water for domestic use. Boreholes are generally considered safer than surface water sources due to natural filtration through soil and rock layers; however, poor construction practices, shallow depths, and proximity to contamination sources can significantly compromise their quality (Afolabi & Olutomilola, 2017).

Groundwater quality is influenced by both natural and anthropogenic factors. Geochemical processes such as mineral dissolution and ion exchange affect physicochemical characteristics, while human activities including improper waste disposal, agricultural practices, septic systems, and industrial discharges contribute to chemical and microbial contamination. Physicochemical parameters such as pH, electrical conductivity, total dissolved solids, turbidity, hardness, and major ions are critical indicators of water suitability for drinking and domestic use. Abnormal levels of these parameters may affect water palatability, corrosiveness, and toxicity, and may also enhance the mobility of heavy metals in groundwater systems (Alao *et al*., 2024).

Heavy metals such as lead, cadmium, iron, copper, and zinc may enter groundwater through natural weathering of rocks or anthropogenic activities. Even at low concentrations, some of these metals pose serious health risks due to their toxicity and tendency to bioaccumulate in human tissues. Prolonged exposure to heavy metals through drinking water has been associated with neurological disorders, kidney damage, and other chronic health effects (Egbueri *et al*., 2020). Bacteriological quality remains the most critical parameter in assessing drinking water safety. The presence of coliform bacteria, particularly *Escherichia coli*, in borehole water indicates faecal contamination and the possible presence of pathogenic microorganisms. Several studies across Nigeria have reported bacteriological contamination of borehole water, often attributed to poor sanitation, leaking septic tanks, and inadequate borehole protection (Akoteyon *et al*., 2011; Ndimbo *et al*., 2022).

The Central Senatorial Zone of Taraba State comprises several semi-urban and rural communities where domestic boreholes serve as the major source of drinking water. Despite heavy reliance on these water sources, there is limited documented information on their physicochemical, bacteriological, and heavy metal quality. This study therefore aims to assess the quality of water from selected domestic boreholes in the Central Senatorial Zone of Taraba State and compare the findings with WHO (2017) and NSDWQ (2007) standards, with a view to evaluating potential public health risks and providing baseline data for water-resource management.

MATERIALS AND METHODS

Study Area

The study was carried out in the Central Senatorial Zone of Taraba State, Nigeria, covering five Local Government Areas (LGAs): Bali, Gashaka, Gassol, Kurmi and Sardauna. The zone experiences a tropical climate characterised by wet and dry seasons and is predominantly dependent on groundwater for domestic water supply. Due to inadequate access to treated pipe-borne water, residents rely largely on domestic boreholes located within residential compounds. Figure 1 shows the study area map.

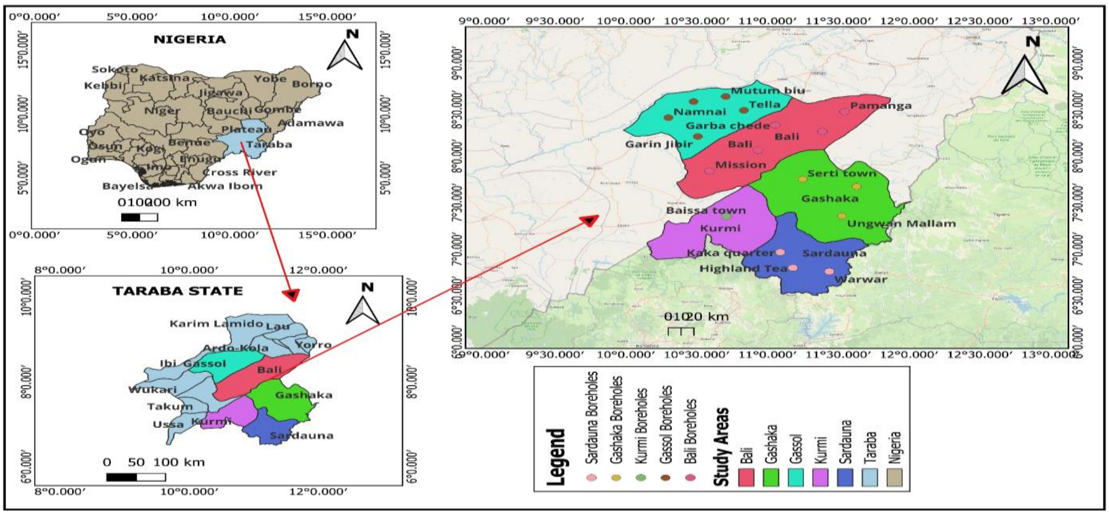

Figure 1: Map of the study area showing the five sampled Local Government Areas

Sample Collection

A total of twenty-five (25) domestic boreholes were sampled, with five (5) boreholes randomly selected from each of the five LGAs based on accessibility, frequency of use, and spatial distribution across each LGA. Sampling was conducted during a single campaign in February 2025 (dry season). At each borehole, one composite sample (1 L) was collected after purging the borehole for 5–10 minutes to obtain fresh, representative groundwater. Samples for physicochemical analysis were collected in pre-cleaned polyethylene bottles rinsed thrice with the sample water, while samples for bacteriological analysis were collected in sterile 250 mL glass bottles. All samples were preserved in ice-packed coolers at 4 °C and transported to the laboratory for analysis within 24 hours of collection (APHA, 2017).

Physicochemical Analyses

Physicochemical parameters were determined following the procedures of APHA (2017). pH, electrical conductivity (EC), total dissolved solids (TDS), salinity and temperature were measured in situ using a calibrated Hanna HI 9829 multi-parameter meter. Turbidity was determined with a HACH 2100Q portable turbidimeter. Colour was measured by the platinum–cobalt visual comparison method. Total alkalinity and total hardness were determined by titrimetric methods (methyl-orange and EDTA titrations, respectively). Chloride was determined by the argentometric (Mohr) titration method. Nitrate was determined spectrophotometrically by the brucine-sulphate method, sulphide by the methylene-blue method, and total chlorine, chlorine dioxide and ozone by the DPD colorimetric method using a HACH DR 3900 spectrophotometer. Phenol was determined by the 4-aminoantipyrine spectrophotometric method, cyanide by the pyridine–barbituric acid method, urea by the diacetyl-monoxime colorimetric method, and aniline by the diazotisation–coupling spectrophotometric method. Heavy metals (Cr, Cd, Ni, Mn, Co) were digested with concentrated HNO_3/$HClO_4$ (4:1 v/v) and quantified using a Buck Scientific 210 VGP Atomic Absorption Spectrophotometer (AAS) at the appropriate wavelengths.

Quality Assurance and Quality Control (QA/QC)

All glassware was acid-washed (10 % HNO_3) and rinsed with deionised water prior to use. Reagents were of analytical grade (Sigma-Aldrich, Merck). For each analytical batch, procedural blanks and matrix spikes were run in triplicate; recoveries for heavy metals ranged from 92 % to 104 %. Calibration curves were prepared from certified reference standards ($r^2 \geq 0.998$). Method detection limits (MDLs) were 0.001 mg/L for Cd, Co and Cr, 0.002 mg/L for Ni and Mn, 0.005 mg/L for phenol and 0.002 mg/L for cyanide. Values reported below MDL are shown as 0.00. Each site value in Table 1 represents a single measurement per borehole location; consequently, standard-deviation notation has been omitted from the presented means.

Bacteriological Analyses

Bacteriological analyses were performed using the membrane-filtration and pour-plate techniques described by APHA (2017) and EPA (2017). Total coliforms and *Escherichia coli* were enumerated on m-Endo Agar LES and Eosin Methylene Blue (EMB) agar, respectively, following filtration of 100 mL of sample through a 0.45 µm membrane. *Salmonella–Shigella* counts were determined on Salmonella–Shigella Agar (SSA), *Bacillus subtilis* on Nutrient Agar, and total heterotrophic bacteria on Plate Count Agar (PCA). All plates were incubated at 37 °C for 24–48 h and counts expressed as colony-forming units per 100 mL (cfu/100 mL).

Water Quality Index (CCME WQI)

Overall water quality at each site was evaluated using the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) (CCME, 2017). The index is based on three factors: Scope (F_1) the percentage of parameters that exceed their guideline value; Frequency (F_2) the percentage of individual tests that fail; and Amplitude (F_3) the extent by which failed test values depart from their guidelines. The index is computed as:

$$\text{CCME WQI (\%)} = 100 - [\sqrt{(F_1^2 + F_2^2 + F_3^2)} / 1.732] \quad (1)$$

Resulting values range from 0 to 100, with higher values indicating better water quality. The computed indices were interpreted using the classification in Table 2 (CCME, 2017; Ravikumar *et al*., 2020).

Statistical Analysis

Descriptive statistics (range and mean) were computed for each parameter using Microsoft Excel 2019. Because only one sample per borehole was analysed in this reconnaissance survey, inferential statistics (e.g., ANOVA) among LGAs were not performed; comparisons among sites are therefore descriptive only, and differences are discussed cautiously as apparent variations rather than statistically significant differences. This limitation is acknowledged, and future work will incorporate replicate sampling across seasons to permit formal statistical inference.

Table 1: CCME Water Quality Index (WQI) Classification Scheme

CCME WQI Value	Rating	Description
95 – 100	Excellent	Water quality is protected with little or no impairment
80 – 94	Good	Water quality is protected with a minor degree of impairment
65 – 79	Fair	Water quality is occasionally threatened
45 – 64	Marginal	Water quality is frequently threatened
0 – 44	Poor	Water quality is almost always threatened

RESULTS AND DISCUSSION

Physicochemical Quality of Borehole Water

The physicochemical characteristics of borehole water from Bali, Gashaka, Gassol, Kurmi and Sardauna LGAs are presented in Table 1. Apparent variations across locations reflect differences in local geology, land use and possible anthropogenic influences; because only one sample per borehole was analysed, these variations are described qualitatively and not tested for statistical significance.

Table 2: Physicochemical Parameters of Borehole Water from the Central Senatorial Zone of Taraba State (Single Measurement per Site)

S/N	Parameter	Bali	Gashaka	Gassol	Kurmi	Sardauna	WHO (2017)
1	pH	6.55±0.00	6.84±0.00	6.09±0.00	7.43±0.00	6.89±0.00	6.5 – 8.5
2	Colour (ptCo)	0.00±0.00	0.00±0.00	0.00±0.00	3.00±0.00	7.00±0.00	15
3	Temperature (°C)	32.20±0.00	32.40±0.00	33.00±0.00	28.10±0.00	30.10±0.00	Ambient
4	Electrical Conductivity (µS/cm)	427.00±0.00	184.70±0.00	209.00±0.00	413.00±0.00	287.00±0.00	1000
5	Turbidity (NTU)	1.72±0.00	0.946±0.00	3.44±0.00	0.135±0.00	2.14±0.00	5
6	Total Dissolved Solids (mg/L)	341.60±0.00	147.76±0.00	167.20±0.00	330.40±0.00	229.60±0.00	500
7	Salinity (mg/L)	234.85±0.00	101.59±0.00	114.95±0.00	227.15±0.00	157.85±0.00	500
8	Total Chlorine (mg/L)	0.15±0.00	0.22±0.00	0.13±0.00	0.13±0.00±0.00	0.10±0.00	4
9	Alkalinity (mg/L)	130.00±0.00	90.00±0.00	60.00±0.00	60.00±0.00	45.00±0.00	200
10	Total Hardness (mg/L)	50.00±0.00	40.00±0.00	80.00±0.00	50.00±0.00	50.00±0.00	120
11	Chlorine Dioxide (mg/L)	0.67±0.00	0.51±0.00	0.45±0.00	0.32±0.00	0.05±0.00	0.05
12	Ozone (mg/L)	0.30±0.00	0.16±0.00	0.14±0.00	0.16±0.00	0.13±0.00	1.2
13	Chloride (mg/L)	129.99±0.00	56.23±0.00	63.63±0.00	125.73±0.00	87.37±0.00	250
14	Sulphide (mg/L)	0.00±0.00	0.00±0.00	0.00±0.00	0.02±0.00	0.00±0.00	0.05
15	Nitrate (mg/L)	7.97±0.00	3.16±0.00	8.30±0.00	27.88±0.00	12.91±0.00	50
16	Cyanide (mg/L)	0.00±0.00	0.00±0.00	0.00±0.00	0.03±0.00	0.08±0.00	0.07
17	Aniline (mg/L)	0.27±0.00	0.71±0.00	1.31±0.00	0.00±0.00	1.89±0.00	4
18	Urea (mg/L)	0.00±0.00	0.00±0.00	0.00±0.00	0.11±0.00	0.00±0.00	0
19	Phenol (mg/L)	0.00±0.00	0.00±0.00	0.00±0.00	0.06±0.00	1.00±0.00	0.1
20	Chromium (mg/L)	0.00±0.00	0.02±0.00	0.02±0.00	0.00±0.00	0.28±0.00	0.05
21	Cadmium (mg/L)	0.00±0.00	0.00±0.00	0.00±0.00	0.01±0.00	0.01±0.00	0.005
22	Nickel (mg/L)	0.00±0.00	2.33±0.00	0.77±0.00	0.00±0.00	2.63±0.00	0.02
23	Manganese (mg/L)	0.00±0.00	0.00±0.00	0.00±0.00	0.13±0.00	1.83±0.00	3
24	Cobalt (mg/L)	0.0141±0.00	0.0106±0.00	0.0106±0.00	0.0000±0.00	0.0000±0.00	0.1

Table 2 above shows the pH values ranged from 6.09 (Gassol) to 7.43 (Kurmi), all within the WHO (2017) permissible range of 6.5–8.5, indicating that the groundwater is generally suitable for domestic use in terms of acidity/alkalinity. The slightly acidic to neutral character is consistent with dissolution of atmospheric CO_2 and interaction with local aquifer materials. Comparable pH ranges have been reported for Nigerian groundwater by Ademoroti (1996) and Kayode *et al*. (2024).

Colour values (0.00–7.00 ptCo), turbidity (0.14–3.44 NTU), electrical conductivity (184.70–427.00 µS/cm), total dissolved solids (147.76–341.60 mg/L) and salinity (101.59–234.85 mg/L) were all below their respective WHO limits, indicating fresh, moderately mineralised groundwater consistent with earlier reports for Nigerian aquifers (Akoteyon *et al*., 2011; Egbueri, 2020; Igwe *et al*., 2021).

Temperature values (28.10–33.00 °C) reflect typical tropical shallow groundwater conditions (Igwe *et al*., 2021). Alkalinity (45.00–130.00 mg/L) and total hardness (40.00–80.00 mg/L) were below WHO limits, classifying the water as soft to moderately hard.

Chloride (56.23–129.99 mg/L) and sulphide (≤ 0.02 mg/L) were below WHO limits at all sites, indicating negligible saline or anaerobic-organic contamination (Ademoroti, 1996; APHA, 2017).

Nitrate ranged from 3.16 mg/L (Gashaka) to 27.88 mg/L (Kurmi); although all values remained below the WHO limit of 50 mg/L, the comparatively higher level in Kurmi may reflect infiltration of nitrogenous fertilisers and on-site sanitation, a pattern also noted for Nigerian farmlands by Egbueri (2020).

Cyanide reached 0.08 mg/L in Sardauna, marginally exceeding the WHO limit of 0.07 mg/L, while remaining below the limit or undetected elsewhere. This localised elevation may reflect anthropogenic inputs or geochemical processes and warrants further investigation (WHO, 2017). Aniline (0.00–1.89 mg/L) and urea (0.00–0.11 mg/L) were within acceptable ranges but their occurrence at some sites hints at possible agricultural or domestic organic inputs (Ademoroti, 1996).

Phenol reached 1.00 mg/L in Sardauna and 0.06 mg/L in Kurmi; the Sardauna value greatly exceeds the WHO limit of 0.1 mg/L and may reflect organic pollution from domestic or agricultural waste (WHO, 2017). Chromium (0.28 mg/L, Sardauna), cadmium (0.01 mg/L, Kurmi and Sardauna) and nickel (2.33 mg/L, Gashaka; 2.63 mg/L, Sardauna) exceeded their respective WHO limits of 0.05, 0.005 and 0.02 mg/L. These elevations may originate from natural weathering of ferromagnesian minerals and/or corrosion of borehole casings and anthropogenic waste inputs, and are of health concern given the toxicity and bioaccumulative potential of these metals (Egbueri *et al*., 2020; Kayode *et al*., 2024). Manganese (≤ 1.83 mg/L) and cobalt (≤ 0.0141 mg/L) remained within WHO limits at all sites.

Bacteriological Quality of Borehole Water

The bacteriological results are summarised in Table 3.

Table 3: Bacteriological parameters (cfu/100 mL) of borehole water from the Central Senatorial Zone of Taraba State

S/N	Parameter	Bali	Gashaka	Gassol	Kurmi	Sardauna	WHO/NSDWQ
1	Total coliforms	50	70	30	300	323	10
2	Escherichia coli	29	15	18	50	28	0
3	Salmonella–Shigella	12	3	13	40	35	0
4	Bacillus subtilis	30	0	6	3	7	0
5	Total heterotrophic count	42	68	28	200	400	15

Table 3 shows that the total coliform counts (30–323 cfu/100 mL), *E. coli* (15–50 cfu/100 mL), *Salmonella–Shigella* (3–40 cfu/100 mL) and total heterotrophic bacteria (28–400 cfu/100 mL) exceeded the WHO and NSDWQ guideline values for potable water at all sites, indicating widespread faecal contamination. The presence of *E. coli* a specific indicator of recent faecal pollution strongly suggests infiltration of human or animal waste, most likely from nearby pit latrines, septic systems and surface runoff (Akoteyon *et al*., 2011; Ndimbo *et al*., 2022). *Bacillus subtilis* (0–30 cfu/100 mL), a spore-forming soil organism, reflects contact between the aquifer and surface soils, consistent with poor wellhead protection (Ademoroti, 1996). Overall, the borehole water sources cannot be considered microbiologically safe without prior treatment.

Overall Water Quality (CCME WQI)

Table 4: CCME Water Quality Index (WQI) Results for the Sampled Local Government Areas

S/N	Sampling site	Scope (F_1)	Frequency (F_2)	Amplitude (F_3)	CCME WQI (%)	Rating
1	Bali	18.51851852	18.51851852	99.99619734	40.32	Poor
2	Gashaka	23.07692328	23.07692308	99.98556824	39.27	Poor
3	Gassol	22.22222222	22.22222222	99.99270397	39.48	Poor
4	Kurmi	25	25	99.99741953	38.76	Poor
5	Sardauna	37.03703704	37.03703704	99.9961441	34.82	Poor

All five LGAs fell within the "poor" CCME WQI category (34.82–40.32), reflecting frequent impairment driven mainly by microbial contamination and by exceedances of nickel, chromium, cadmium, phenol and cyanide at specific sites.

CONCLUSION

This study assessed the physicochemical and bacteriological quality of 25 domestic boreholes across five Local Government Areas of the Central Senatorial Zone of Taraba State. Most physicochemical parameters (pH, colour, turbidity, EC, TDS, salinity, alkalinity, hardness, chloride, sulphide, nitrate and manganese) were within WHO and NSDWQ limits. However, phenol, cyanide, chromium, cadmium and nickel exceeded permissible limits at one or more sites most notably in Sardauna and, for cadmium and nitrate, in Kurmi. All sampling locations returned bacteriological counts (total coliforms, E. coli, Salmonella–Shigella and total heterotrophic bacteria) far above WHO/NSDWQ guideline values, indicating faecal contamination.

The CCME WQI classified all five LGAs as "poor" (Bali 40.32, Gashaka 39.27, Gassol 39.48, Kurmi 38.76, Sardauna 34.82). The borehole waters are therefore unsuitable for direct human consumption. Priority remediation should focus on: (i) removal of nickel, chromium and cadmium (e.g., ion-exchange, adsorption on low-cost sorbents or reverse osmosis at community level); (ii) treatment of phenol and cyanide-affected supplies in Sardauna by activated-carbon adsorption or advanced oxidation; and (iii) point-of-use disinfection (chlorination, boiling or ceramic/biosand filtration) to eliminate faecal indicator organisms. Wellhead protection, relocation of pit latrines away from boreholes, and routine (at least seasonal) monitoring of borehole water quality are strongly recommended.

REFERENCES

Ademoroti, C. M. A. (1996). *Standard methods for water and effluent analysis (1st ed.)*. Foludex Press, Ibadan, Nigeria.

Afolabi, O. O., & Olutomilola, O. O. (2017). Hydrogeochemical assessment of groundwater quality in Ado-Ekiti Metropolis, South-Western Nigeria. *Water Resources Journal of the Nigerian Association of Hydrogeologists*, 27, 1–14.

Akoteyon, I. S., Omotayo, A. O., Soladoye, O., & Olaoye, H. O. (2011). Determination of water quality index and suitability of urban river for municipal water supply in Lagos, Nigeria. *European Journal of Scientific Research*, 54(2), 263–271.

Alao, J. O., Lawal, H. A., Abubakar, F., & Abdulsalami, M. (2024). Geophysical and physicochemical assessment of groundwater and the implication on public health in rural and semi-urban areas of Northern Nigeria. *Discover Environment*, 2(1), 44. https://doi.org/10.1007/s44274-024-00069-7

American Public Health Association (APHA). (2017). *Standard methods for the examination of water and wastewater (23rd ed.)*. APHA, AWWA and WEF, Washington, DC.

Canadian Council of Ministers of the Environment (CCME). (2017). *Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index 1.0 Technical report*. CCME, Winnipeg, Canada. https://ccme.ca/en/resources/water

Edokpayi, J. N., Odiyo, J. O., & Durowoju, O. S. (2017). *Impact of wastewater on surface water quality in developing countries: A case study of South Africa*. In Water Quality (pp. 401–416). IntechOpen. https://doi.org/10.5772/66561

Edwin, N., Ibiam, U. A., Okorie-Igwenyi, I., Ude, V. C., & Eko, S. N. (2015). Evaluation of physicochemical properties, mineral and heavy-metal content of drinking-water samples in two communities in South-East Nigeria: A public-health implication. *International Journal of Current Research*, 5(9), 2564–2571.

Egbueri, J. C. (2020). Groundwater quality assessment using pollution index of groundwater (PIG), ecological risk index (ERI) and hierarchical cluster analysis (HCA): A case study. *Groundwater for Sustainable Development*, 10, 100292. https://doi.org/10.1016/j.gsd.2019.100292

Egbueri, J. C., Ezugwu, C. K., Ameh, P. D., Unigwe, C. O., & Ayejoto, D. A. (2020). Appraising drinking-water quality in Ikem rural area (Nigeria) based on chemometrics and multiple indexical methods. *Environmental Monitoring and Assessment*, 192(5), 308. https://doi.org/10.1007/s10661-020-08277-3

Environmental Protection Agency (EPA). (2017). Method 1604: Total coliforms and Escherichia coli in water by membrane filtration using a simultaneous detection technique. *United States Environmental Protection Agency, Washington, DC.* https://www.epa.gov/cwa-methods

Gyamfi, E. T., Ackah, M., Anim, A. K., Hanson, J. K., Kpattah, L., Enti-Brown, S., & Nyarko, E. S. (2012). Chemical analysis of potable water samples from selected suburbs of Accra, Ghana. *Proceedings of the International Academy of Ecology and Environmental Sciences*, 2(2), 118–127.

Igwe, O., Ngwoke, M., Ukah, B. U., & Ubido, O. E. (2021). Assessment of the physicochemical qualities of groundwater and soils around oil-producing communities in Afam, area of Port Harcourt, Niger Delta, Nigeria. *Applied Water Science*, 11(4), 74. https://doi.org/10.1007/s13201-021-01402-8

Isah, A., Akinbiyi, O. A., Ugwoke, J. L., Ayajuru, N. C., & Oyelola, R. O. (2023). Detection of groundwater level and heavy-metal contamination: A case study of Olubunku dumpsite and environs, Ede North, Southwestern Nigeria. *Journal of African Earth Sciences*, 197, 104740. https://doi.org/10.1016/j.jafrearsci.2022.104740

Jaji, M. O., Bamgbose, O., Odukoya, O. O., & Arowolo, T. A. (2007). Water-quality assessment of Ogun River, South West Nigeria. *Environmental Monitoring and Assessment*, 133(1), 473–482. https://doi.org/10.1007/s10661-006-9602-1

Kayode, M. O., Tomori, W. B., Okoronkwo, E. A., & Adiat, K. A. N. (2024). Seasonal variation of groundwater quality in a basement-complex geology of Ado-Ekiti, Nigeria, using a water-quality-index model. *Journal of Umm Al-Qura University for Applied Sciences*, 10, 1–26. https://doi.org/10.1007/s43994-024-00133-1

Ndimbo, A., Mbuligwe, S., & Mbuna, J. (2022). Physicochemical characteristics and heavy-metal levels in groundwater from selected areas of Dar es Salaam City, Tanzania. *Tanzania Journal of Science*, 48(2), 26–43. https://doi.org/10.4314/tjs.v48i2.4

Nigerian Standard for Drinking Water Quality (NSDWQ). (2007). Nigerian standard for drinking water quality. Nigerian Industrial Standard, NIS 554, 13–14. Standards Organisation of Nigeria, Lagos.

Obiefuna, G. I., Sini, P. H., & Maunde, A. (2019). Hydrogeochemical evaluation of groundwater quality in parts of North-Eastern Nigeria. *International Journal of Research Publications*, 30(1), 1–15.

Popoola, L. T., Yusuff, A. S., & Aderibigbe, T. A. (2019). Assessment of natural groundwater physico-chemical properties in major industrial and residential locations of Lagos metropolis. *Applied Water Science*, 9(8), 191. https://doi.org/10.1007/s13201-019-1073-y

Ravikumar, P., Somashekar, R. K., & Prakash, K. L. (2020). A comparative study on usage of Durov and Piper diagrams to interpret hydrochemical processes in groundwater. *Environmental Earth Sciences*, 79(5), 121. https://doi.org/10.1007/s12665-020-8873-0

Shuaibu, A., Hounkpè, J., Bossa, Y. A., & Kalin, R. M. (2024). Application of the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) for groundwater-quality assessment: A review. *Environmental Monitoring and Assessment*, 196(4), 305. https://doi.org/10.1007/s10661-024-12456-x

World Health Organization (WHO). (2017). *Guidelines for drinking-water quality* (4th ed., incorporating the 1st addendum). WHO, Geneva.

Yusuf, J., Kalip, A., & Aremu, S. O. (2024). Evaluation of heavy metals' concentration and physicochemical parameters of groundwater within Jos Metropolis of Plateau State, Nigeria. *FUDMA Journal of Sciences*, 8(2), 373–381. https://doi.org/10.33003/fjs-2024-0802-2345