



Research Article

Physicochemical Characteristics, Heavy Metal Pollution, and Microbial Safety of Drinking Water Sources in Dutsin-Ma, Katsina State, Nigeria

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ABSTRACT

Access to microbiologically and chemically safe drinking water remains a critical public health challenge in many semi-arid communities of northern Nigeria. This study evaluated the physicochemical characteristics, heavy metal contamination, and microbial quality of groundwater sources in three locations Darawa, Miami, and Bayan Gidan Radio within Dutsin-Ma metropolis, Katsina State, Nigeria. Nine borehole water samples were collected and analysed using standard procedures recommended by the American Public Health Association (APHA, 2017). Physicochemical parameters including pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), nitrate, and sulphate were determined using calibrated field and laboratory instruments. Concentrations of lead (Pb), cadmium (Cd), and copper (Cu) were quantified using atomic absorption spectrophotometry (AAS). Microbial quality was assessed by detecting *Escherichia coli* and total coliform bacteria using selective culture media. Results revealed notable spatial variations in water quality across the study areas. All samples exceeded World Health Organization (WHO) permissible limits for turbidity, lead, and cadmium, signifying potential long-term public health risks. Copper concentrations remained within acceptable limits in all locations. Microbial analysis detected *E. coli* and total coliforms in samples from Miami and Bayan Gidan Radio, suggesting faecal contamination, while Darawa samples showed no detectable microbial contamination. The co-occurrence of toxic heavy metals and microbial contaminants in several locations presents a compounded public health risk. Continuous water quality monitoring, adequate treatment interventions, and improved sanitation infrastructure are strongly recommended to ensure safe drinking water provision in Dutsin-Ma metropolis.

Keywords: Cadmium; Coliform bacteria; Drinking water quality; *Escherichia coli*; Groundwater contamination; Heavy metals; Public health risk

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INTRODUCTION

Access to safe and potable drinking water is fundamental to human health, socioeconomic well-being, and the attainment of the United Nations Sustainable Development Goal 6 (World Health Organization (WHO), 2017). In many developing countries, particularly in the semi-arid regions of northern Nigeria, groundwater sourced from boreholes constitutes the principal supply of drinking

and domestic water (Adebanjo, 2021; Okareh *et al.*, 2023). Despite its widespread use, groundwater quality is increasingly compromised by both natural geological processes and anthropogenic activities, including urban expansion, agricultural practices, improper waste disposal, and inadequate sanitation infrastructure (Alloway *et al.*, 2022; Chinye-Ikejior *et al.*, 2021).

Physicochemical and microbiological parameters are widely employed as indicators for assessing the suitability of water for human consumption. Parameters such as pH, electrical conductivity, total dissolved solids (TDS), turbidity, dissolved oxygen (DO), and biochemical oxygen demand (BOD) provide important insights into the general quality of water, while heavy metal concentrations and the presence of pathogenic microorganisms directly reflect potential health hazards (APHA, 2017; WHO, 2017). Heavy metals are of particular concern due to their persistence in the environment, non-biodegradable nature, and tendency to bioaccumulate in biological tissues (Tchounwou *et al.*, 2012; Mitra *et al.*, 2022). Lead (Pb) and cadmium (Cd) are among the most hazardous non-essential heavy metals. Chronic exposure to lead-contaminated water has been associated with irreversible neurodevelopmental impairment in children, cardiovascular disorders, renal dysfunction, and increased cancer risk (WHO, 2023; Naranjo *et al.*, 2020). The WHO has affirmed that there is no known safe blood lead concentration, as even low levels are linked to intellectual deficits and behavioural disorders in children (WHO, 2023). Similarly, cadmium exposure is documented to cause kidney damage, bone demineralisation (itai-itai disease), and carcinogenic effects (Sable *et al.*, 2024; Mitra *et al.*, 2022). Although copper (Cu) is an essential micronutrient, excessive dietary intake through contaminated water may produce gastrointestinal disturbances (Alloway *et al.*, 2022). In addition to chemical contamination, microbial pollution of drinking water continues to be a major public health challenge in Nigerian communities, frequently resulting from faecal contamination associated with inadequate sanitation (Rabiu *et al.*, 2022; Usman and Aliyu, 2025). *Escherichia coli* and total coliform bacteria serve as widely accepted faecal indicator organisms, signalling the possible presence of pathogenic microorganisms capable of causing waterborne diseases such as diarrhoea, typhoid fever, and cholera (Frontiers in Water, 2025; Rabiu *et al.*, 2022).

In Dutsin-Ma metropolis, rapid population growth and the intensification of human activities have heightened concerns about groundwater safety. However, comprehensive data on the combined physicochemical, heavy metal, and microbial quality of drinking water in this locality remain scarce. This study therefore aims to provide an integrated assessment of drinking water quality in selected locations within Dutsin-Ma, thereby generating

empirical evidence for water resource management, policy formulation, and public health protection.

Despite widespread reliance on groundwater for domestic and drinking water purposes in Dutsin-Ma metropolis, there is insufficient scientific documentation of its chemical and microbiological safety. The increasing intensity of human activities including agriculture, solid waste disposal, and urban development raises the probability of groundwater contamination by toxic heavy metals and pathogenic microorganisms. Without adequate monitoring and systematic data collection, residents may unknowingly consume unsafe water, thereby exposing themselves to serious chronic and acute health consequences. This lack of comprehensive water quality assessment justifies the need for the present investigation.

The assessment of drinking water quality is essential for safeguarding public health and ensuring sustainable management of water resources (WHO, 2017). Heavy metal contamination of drinking water has been linked to chronic kidney failure, neurological impairment, and elevated cancer risk (Mitra *et al.*, 2022; WHO, 2023). Microbial contamination equally poses acute risks, with waterborne diseases accounting for a significant proportion of morbidity and mortality in developing countries with inadequate sanitation infrastructure (Rabiu *et al.*, 2022; WHO, 2017). Lead exposure alone was estimated to account for approximately 21.7 million disability-adjusted life years (DALYs) globally in 2019 (WHO, 2023).

This study provides empirical data on the quality of groundwater in Dutsin-Ma metropolis and identifies health risks associated with its consumption. The study contributes to the achievement of Sustainable Development Goal 6 (SDG 6), which seeks to ensure universal access to safe and affordable drinking water by 2030 (WHO, 2017). Hence, this study is to evaluate the physicochemical characteristics, heavy metal contamination, and microbial safety of drinking water sources in Dutsin-Ma metropolis, Katsina State, Nigeria.

MATERIALS AND METHODS

Study Area

The study was conducted in Dutsin-Ma metropolis, Katsina State, northern Nigeria. Dutsin-Ma is a semi-arid town characterised by limited surface water availability, making groundwater the predominant source of domestic and drinking water for its residents. Three residential locations were selected based on population density and water usage

patterns: Darawa (Sample A), Miami (Sample B), and Bayan Gidan Radio (Sample C). The locations differ in terms of proximity to agricultural fields, informal waste disposal sites, and sanitation infrastructure.

Research Design and Sample Collection

A cross-sectional study design was adopted. Nine groundwater samples were collected from boreholes across the three locations (three samples per location) using pre-cleaned high-density polyethylene (HDPE) bottles. Prior to sample collection, bottles were triple-rinsed with sample water at the point of collection. Samples designated for heavy metal analysis were acidified in situ with concentrated nitric acid (HNO₃) to pH < 2 to prevent metal adsorption onto container walls, in strict accordance with APHA (2017) standard procedures. Samples for microbial analysis were collected aseptically into sterile glass bottles and transported to the laboratory on ice within six hours of collection for analysis.

Physicochemical Analysis

Parameters including pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), nitrate, and sulphate were determined using calibrated field instruments and standard analytical methods recommended by APHA (2008, 2015 & 2017). pH and temperature were measured in situ using a calibrated digital pH/temperature meter. EC and TDS were determined using a portable conductivity meter. Turbidity was measured with a calibrated nephelometer. DO and BOD were determined using the azide modification of the Winkler method. Nitrate and sulphate were determined spectrophotometrically.

Heavy Metal Analysis

Water samples were subjected to acid digestion using a mixture of concentrated nitric acid (HNO₃) and hydrochloric acid (HCl) prior to analysis, following AOAC (2004) procedures. Concentrations of lead (Pb), cadmium (Cd), and copper (Cu) were determined by flame atomic absorption spectrophotometry (AAS) after calibration with certified reference standards (1000 mg/L stock solutions, analytically pure grade), in accordance with AOAC (2004) and APHA (2017) guidelines. All analyses were performed in triplicate and results expressed as mean values in mg/L. Method detection limits were established for each metal prior to sample analysis.

Microbial Analysis

Microbial quality was assessed using culture-based methods recommended by APHA (2017). Water samples were serially diluted and plated on MacConkey agar for the detection and enumeration

of total coliform bacteria, and on Eosin Methylene Blue (EMB) agar for the identification of *Escherichia coli*. Plates were incubated at 37°C for 24–48 hours. Colony counts were recorded and characteristic metallic-green sheen colonies on EMB agar were confirmed as *E. coli* based on colonial morphology and standard biochemical tests including indole production, methyl red reaction, Voges-Proskauer test, and citrate utilisation (IMViC tests). Results were expressed as colony-forming units per millilitre (cfu/mL).

Data Analysis

All physicochemical and heavy metal measurements were performed in triplicate. Data were expressed as mean ± standard deviation (SD). Measured values were compared against WHO (2017) guideline values for drinking water quality. Spatial variations across sampling locations were assessed by descriptive comparison.

RESULTS

Physicochemical Parameters and Heavy Metal Concentrations

The physicochemical parameters and heavy metal concentrations of groundwater samples from Darawa (Sample A), Miami (Sample B), and Bayan Gidan Radio (Sample C) are presented in Table 1. All parameters are compared with WHO (2017) guideline values for drinking water quality.

As shown in **Table 1**, pH values were within the WHO acceptable range of 6.5–8.5 for all samples. Electrical conductivity and TDS values were well below the respective guideline limits of 1000 µS/cm and 500 mg/L across all three locations, indicating low mineralisation of the groundwater. However, turbidity values exceeded the WHO guideline limit of 5 NTU in all locations, with Darawa recording an exceptionally high value of 70.0 NTU, suggesting substantial particulate loading and potential interference with disinfection processes.

Lead concentrations exceeded the WHO permissible limit of 0.01 mg/L by more than 100-fold in all sampled locations, ranging from 1.057 mg/L (Sample C) to 1.241 mg/L (Sample A). Similarly, cadmium concentrations in all samples surpassed the WHO guideline of 0.003 mg/L, with values ranging from 0.014 mg/L to 0.023 mg/L. Copper concentrations in all samples were below the WHO guideline value of 2.0 mg/L.

Microbial Quality of Groundwater Samples

The results of microbial analysis of the groundwater samples are summarised in Table 2. *Escherichia coli* and total coliform bacteria were not detected in any

Darawa (Sample A) samples at any tested concentration. In contrast, *E. coli* was detected in samples from Miami (Sample B) and Bayan Gidan Radio (Sample C) at the highest concentration tested (1000 µL/mL). Total coliform bacteria were

additionally detected at concentrations of 1000 µL/mL and 500 µL/mL in Bayan Gidan Radio samples, indicating a higher degree of faecal contamination relative to the other locations.

Table 1. Physicochemical parameters and heavy metal concentrations of groundwater samples from Dutsin-Ma metropolis compared with WHO (2017) guideline values

Parameter	Darawa	Miami	Bayan Gidan Radio	WHO Guideline Value	Remark
pH	7.2	6.9	7.0	6.5–8.5	Within limit
Temperature (°C)	27.5	28.1	27.8	≤ 30	Within limit
Electrical Conductivity (µS/cm)	6.9	6.1	5.5	≤ 1000	Within limit
Total Dissolved Solids (mg/L)	1.0	0.9	0.9	≤ 500	Within limit
Turbidity (NTU)	70.0	6.8	7.6	≤ 5	Above limit
Dissolved Oxygen (mg/L)	5.2	4.9	5.1	≥ 5	Borderline
BOD (mg/L)	2.1	1.8	1.9	< 5	Within limit
Nitrate (mg/L)	3.4	2.9	3.1	≤ 50	Within limit
Sulphate (mg/L)	12.5	10.2	11.8	≤ 250	Within limit
Lead (mg/L)	1.241	1.179	1.057	0.01	Above limit
Cadmium (mg/L)	0.023	0.018	0.014	0.003	Above limit
Copper (mg/L)	0.152	0.095	0.082	2.0	Within limit

Note: BOD = Biochemical Oxygen Demand; EC = Electrical Conductivity; TDS = Total Dissolved Solids; WHO = World Health Organization. Values are mean of triplicate determinations.

Table 2. Microbial quality of groundwater samples from Dutsin-Ma metropolis at varying concentrations

Location	Microorganism	1000 µL/mL	500 µL/mL	250 µL/mL
Darawa (Sample A)	<i>E. coli</i>	0 (Absent)	0 (Absent)	0 (Absent)
Darawa (Sample A)	Total Coliform	0 (Absent)	0 (Absent)	0 (Absent)
Miami (Sample B)	<i>E. coli</i>	1 (Present)	0 (Absent)	0 (Absent)
Miami (Sample B)	Total Coliform	0 (Absent)	0 (Absent)	0 (Absent)
Bayan Gidan Radio (Sample C)	<i>E. coli</i>	1 (Present)	0 (Absent)	0 (Absent)
Bayan Gidan Radio (Sample C)	Total Coliform	1 (Present)	1 (Present)	0 (Absent)

Note: 0 = Absent; 1 = Present (growth detected). Results indicate presence or absence of organisms at different dilution

DISCUSSION

The physicochemical results of this study demonstrate pronounced spatial variability in groundwater quality within Dutsin-Ma metropolis, reflecting differences in local lithological conditions, land-use patterns, and anthropogenic pressures. The pH values recorded across all sampling locations were within the WHO (2017) acceptable range of 6.5–8.5, consistent with findings reported for borehole waters in comparable semi-arid Nigerian settings (Okareh *et al.*, 2023; Lapworth *et al.*, 2017). The low EC and TDS values suggest limited ionic mineralisation, characteristic of crystalline basement aquifers that predominate in northern Nigeria (Lapworth *et al.*, 2017).

Of notable concern is the extremely high turbidity recorded in Darawa (70.0 NTU), far exceeding the WHO guideline threshold of 5 NTU in all three locations. Elevated turbidity not only compromises

the aesthetic acceptability of water but critically impairs the efficacy of disinfection processes by providing physical protection to microorganisms embedded within suspended particulate matter (WHO, 2017; Sokolova *et al.*, 2022). This finding is consistent with observations by Usman and Aliyu (2025) who reported elevated turbidity in borehole waters across communities in Katsina State linked to anthropogenic disturbances of the aquifer recharge zones.

The consistently elevated lead concentrations observed across all sampling locations exceeding WHO permissible limits by factors of 100 to over 120 represent a critical public health emergency. Lead is a potent cumulative systemic toxicant with no known safe level of exposure (WHO, 2023). Chronic ingestion of lead-contaminated water in children causes irreversible neurodevelopmental damage, manifesting as reduced IQ, impaired cognitive

function, attention deficits, and behavioural disorders (Naranjo *et al.*, 2020; Lidsky and Schneider, 2003). In adults, chronic lead exposure is associated with cardiovascular disease, hypertension, and nephrotoxicity (WHO, 2023). The US EPA has established a maximum contaminant level goal of zero for lead in drinking water, given its well-documented absence of any safe threshold (USEPA, 2019).

Similarly, cadmium levels in all samples exceeded the WHO guideline of 0.003 mg/L. Cadmium is classified as a Group 1 human carcinogen by the International Agency for Research on Cancer (IARC) and is associated with renal tubular dysfunction, osteoporosis, and increased risk of lung and kidney cancers upon chronic exposure (Sable *et al.*, 2024; Mitra *et al.*, 2022). The potential sources of Pb and Cd contamination in Dutsin-Ma groundwater may include natural geological weathering of metal-bearing minerals, surface runoff from agricultural fields where pesticides containing these metals are applied, and leachate from improperly managed solid waste disposal sites in the vicinity of the sampling locations (Alloway *et al.*, 2022; Ojekunle *et al.*, 2022). Copper concentrations across all three locations remained below the WHO guideline value of 2.0 mg/L, indicating no immediate concern from copper exposure. This finding is in agreement with studies on shallow aquifers in other parts of Nigeria, where copper contamination is generally considered a lower priority concern compared to lead and cadmium (Okafor *et al.*, 2023; Lapworth *et al.*, 2017). Nevertheless, periodic monitoring of copper is warranted, as long-term elevated intake can cause gastrointestinal disturbances (Alloway *et al.*, 2022).

The detection of *Escherichia coli* the universal faecal indicator organism in water samples from Miami and Bayan Gidan Radio provides unequivocal evidence of faecal contamination. *E. coli* in drinking water indicates recent faecal pollution and signals the potential presence of other enteric pathogens capable of causing diarrhoeal diseases, typhoid fever, and cholera (Rabiu *et al.*, 2022; PLOS Water, 2026). The additional presence of total coliform bacteria at multiple dilutions in Bayan Gidan Radio samples suggests a higher magnitude of contamination and possible persistent faecal pollution sources in that location.

These findings are consistent with those of Usman and Aliyu (2025), who reported widespread faecal coliform contamination in borehole and well water across communities in Katsina State, linked to the proximity of water sources to pit latrines and open

defecation sites. Similarly, Rabiu *et al.* (2022) demonstrated that borehole water sources in peri-urban communities in Nigeria were significantly contaminated with coliforms and pathogenic *E. coli*, particularly during the wet season. The absence of microbial contamination in Darawa samples may reflect localised hydrogeological advantages, including deeper aquifer penetration, greater distance from sanitation facilities, or more protective overlying soil layers that serve as natural filters (Frontiers in Water, 2025).

The co-occurrence of heavy metal contamination and microbial pollution in Miami and Bayan Gidan Radio presents a compounded public health risk. Heavy metals such as lead are known immunosuppressants that impair both innate and adaptive immune responses, thereby increasing susceptibility to infectious waterborne diseases (Mitra *et al.*, 2022). This synergistic risk underscores the urgent need for integrated water safety management strategies.

CONCLUSION

This study has demonstrated that groundwater sources in Dutsin-Ma metropolis are affected by varying but alarming degrees of physicochemical alteration, heavy metal contamination, and microbial pollution. Lead and cadmium concentrations exceeded WHO permissible limits in all three sampled locations, posing serious long-term health risks to the consuming population, particularly children and vulnerable groups. Turbidity exceeded acceptable limits in all locations, with the Darawa location recording extremely high values. Copper concentrations were within safe limits across all locations. Microbial contamination evidenced by the detection of *Escherichia coli* and total coliform bacteria in Miami and Bayan Gidan Radio further compromises the safety of these water sources and signals active faecal contamination pathways.

These findings provide an integrated assessment of drinking water quality in this important semi-arid metropolis and highlight critical gaps in water safety management. Based on the evidence presented, the following recommendations are made: (i) immediate implementation of point-of-use water treatment technologies (e.g., membrane filtration, coagulation-flocculation for turbidity removal, and reverse osmosis for heavy metal reduction) in affected communities; (ii) routine monitoring of water quality parameters, including heavy metals and microbial indicators, on a seasonal basis; (iii) enforcement of minimum separation distances between borehole installations and sanitation facilities, in conformity

with WHO guidelines; (iv) community-based health education campaigns on safe water handling and hygiene promotion; and (v) policy-level interventions to restrict anthropogenic activities that contribute to aquifer contamination in the recharge zones of Dutsin-Ma metropolis.

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