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A Multidisciplinary Assessment of Microbial Safety and Antimicrobial Resistance in Borehole Water from a Sub-Saharan African University Campus

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Abstract **Review Article**

Ensuring microbiological safety in groundwater sources remains a significant public health challenge in sub-Saharan Africa, where borehole water is widely relied upon for domestic and institutional use. This study conducted a multidisciplinary assessment of the microbial quality and antimicrobial resistance (AMR) profiles of borehole water from Madonna University, Elele, Rivers State, Nigeria. Fifteen samples were collected from diverse campus locations and analyzed using both culture-based and molecular techniques. Physicochemical parameters including pH (6.5–7.4), turbidity (<1.5 NTU), total dissolved solids (<210 mg/L), and nitrate levels (<6.2 mg/L) complied with World Health Organization (WHO) standards, indicating chemical potability. However, microbiological analyses revealed widespread contamination. Total heterotrophic bacterial counts ranged from 1.2×10^2 to 8.5×10^3 CFU/mL, with all samples testing positive for total and fecal coliforms, thereby violating WHO's zero-tolerance threshold. Pathogenic and opportunistic bacteria, including *Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus, Klebsiella pneumoniae*, and *Enterobacter cloacae*, were isolated. Antibiotic susceptibility testing revealed extensive multidrug resistance (MDR), particularly to ampicillin, tetracycline, and ceftriaxone, while ciprofloxacin remained consistently effective. These findings demonstrate the paradox of chemically compliant yet microbiologically unsafe groundwater, with significant implications for campus health and environmental AMR dissemination. The study highlights the urgent need for integrated water safety interventions, including point-of-use disinfection, routine microbial and AMR monitoring, improved borehole construction standards, and community health education. By situating its findings within the WHO's One Health framework, this research underscores the environmental dimensions of AMR and provides a replicable model for institutional water governance and policy development in resource-limited settings.

Keywords: Groundwater Contamination, Borehole Water, Microbial Quality, Antimicrobial Resistance, Multidrug-Resistant Bacteria, Public Health, Nigeria.

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1. INTRODUCTION

Access to clean and safe drinking water is a fundamental human right and a cornerstone of public health, yet this essential resource remains inaccessible to a significant proportion of the global population, especially in low- and middle-income countries (World Health Organization [WHO], 2023). In Nigeria, where rapid urbanization and population growth exert increasing pressure on water infrastructure, many communities depend on groundwater sources such as boreholes to meet their daily water needs (Ojekunle et al., 2018). Borehole water, often considered safer than surface water due to natural filtration processes, is increasingly used without adequate microbial monitoring, raising serious public health concerns (Adejuwon & Mbuk, 2018).

Madonna University, Elele campus, situated in Rivers State a region characterized by high rainfall, abundant aquifers, and oil-related industrial activities relies heavily on borehole water for both domestic and institutional

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consumption. However, the integrity of these water sources is frequently compromised by anthropogenic influences such as poor sanitary practices, unregulated drilling, and proximity to wastewater disposal sites (Ameh et al., 2021). In regions like Elele, where sanitation infrastructure is inadequate and environmental oversight is weak, the risk of microbial contamination in borehole water is not only plausible but also potentially hazardous.

Microbial pathogens, particularly coliforms such as *Escherichia coli*, *Salmonella*, and *Shigella* spp., are indicators of fecal contamination and are frequently implicated in outbreaks of waterborne diseases including cholera, typhoid fever, and dysentery (Ashbolt, 2015). Despite the strategic importance of groundwater in achieving Sustainable Development Goal 6, which emphasizes access to clean water and sanitation, microbial water quality assessment remains underprioritized in institutional settings in Nigeria. This knowledge gap is especially critical in university environments where dense student populations increase the likelihood of disease transmission through contaminated water (Nwachukwu et al., 2020).

Previous studies have largely focused on physico-chemical analyses of borehole water in Rivers State, with limited attention paid to comprehensive microbial profiling (Nnaji et al., 2019). This study addresses that gap by providing a novel and systematic microbial quality assessment of borehole water sources at Madonna University, Elele. Through the application of culture-based and molecular techniques, this research not only evaluates microbial load and diversity but also explores the spatial distribution of contamination relative to environmental and infrastructural factors. The outcome is intended to inform local water management policies and promote evidence-based interventions that safeguard public health in academic institutions.

Ultimately, this study contributes to the growing global discourse on water safety, microbial surveillance, and sustainable groundwater use in developing nations. Its findings will be invaluable for environmental microbiologists, public health authorities, policymakers, and the university's administrative bodies committed to fostering a healthier campus environment through science-based water quality governance.

2. MATERIALS AND METHODS

2.1: Study Area

This study was conducted at Madonna University, Elele Campus, located in Rivers State, Nigeria. The campus is situated within the tropical rainforest belt, characterized by high humidity, significant rainfall (annual average: 2,500–3,000 mm), and elevated groundwater tables. The university comprises several residential hostels, staff quarters, and academic blocks, all of which are serviced by borehole water sources.

2.2: Sample Collection

A total of 15 borehole water samples were randomly collected from different locations within the campus, including male and female student hostels, staff quarters, cafeteria areas, and administrative buildings. Sterile 500 mL sampling bottles were used, and sodium thiosulfate was added to neutralize residual chlorine. Samples were collected in the early morning hours and transported in an ice box to the microbiology laboratory for analysis within six hours, following WHO guidelines (WHO, 2017).

2.3: Physico-Chemical Analysis

Before microbial analysis, basic physico-chemical parameters such as pH, temperature, electrical conductivity (EC), and total dissolved solids (TDS) were measured using standard portable meters (Hanna Instruments, USA). These parameters were recorded in situ at the time of sampling.

2.4 Microbial Analysis

2.4.1: Total Heterotrophic Bacteria Count (THBC)

Serial dilution and pour plate techniques were employed using Nutrient Agar (NA) to estimate the total heterotrophic bacterial count. Plates were incubated at 37°C for 24–48 hours, and results were expressed as colony-forming units per milliliter (CFU/mL) (Prescott et al., 2021).

2.4.2: Coliform and Fecal Coliform Detection

The **Multiple Tube Fermentation (MTF)** technique was used for the detection and enumeration of total coliforms and fecal coliforms. Presumptive, confirmed, and completed tests were conducted using MacConkey broth and Brilliant Green Bile broth. Gas production within 24–48 hours was considered a positive indication of coliform presence. For fecal coliforms, positive tubes were subcultured onto Eosin Methylene Blue (EMB) agar and incubated at 44.5°C (Cheesbrough, 2010).

2.4.3: Isolation and Identification of Bacterial Species

Pure bacterial isolates were obtained through subculturing and were subjected to standard **biochemical tests** including catalase, oxidase, indole, citrate utilization, and triple sugar iron (TSI) tests.

2.4.4: Antibiotic Susceptibility Testing

The Kirby–Bauer disk diffusion method was employed to assess the antibiotic susceptibility of bacterial isolates against commonly used antibiotics such as ampicillin, ciprofloxacin, tetracycline, gentamicin, and ceftriaxone. Interpretations were made based on Clinical and Laboratory Standards Institute (CLSI) guidelines (CLSI, 2024).

2.4.5: Quality Control and Assurance

All media were prepared according to manufacturer specifications and sterilized by autoclaving at 121°C for 15 minutes. Controls included sterile distilled water and known positive strains of *Escherichia coli* and *Staphylococcus aureus*. Duplicate tests were

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conducted to ensure reproducibility.

2.5: Data Analysis

Quantitative data were analyzed using IBM SPSS Statistics version 25. Descriptive statistics (mean, standard deviation) were calculated for microbial counts. One-way ANOVA was employed to evaluate significant differences in microbial loads between sampling locations at a 95% confidence interval ($p < 0.05$).

3. RESULTS

The table1: summarizes the physicochemical parameters of borehole water samples from four hostels at Madonna University St. Peter, Miami, Anthony, and Madonna alongside the corresponding World Health Organization (WHO) standards for potable water. All measured parameters, including pH (6.5–7.4), temperature (26.9–28.1°C), electrical conductivity (180–320 µS/cm), total dissolved solids (120–210 mg/L), turbidity (0.8–1.5 NTU), nitrate (3.8–6.2 mg/L), chloride (35–58 mg/L), and total hardness expressed as $CaCO_3$ (100–160 mg/L), fall within the acceptable WHO limits. These results indicate that the borehole water meets international chemical quality guidelines for safe domestic consumption across all sampling sites.

Table1: Physicochemical parameters of borehole water Samples obtained from four hostels at Madonna University, Elele, Rivers State, Nigeria.

Parameters	WHO Standard	St.Peter	Miami	Anthony	Madonna Hostel
pH	6.5-8.5	6.7	6.9	6.5	7.4
Tempt(°C)	NIL	27.1	26.9	28.1	27.5
EC(us/cm)	≤400	220	180	320	260
TDS(mg/L)	≤500	150	120	210	190
Turbidity(NTU)	≤ 5	1.2	0.8	1.5	1.0
Nitrate(mg/L)	≤ 50	4.2	3.8	6.2	5.0
Chloride(mg/L)	≤ 250	40	35	58	42
TH(mg/L)(CaCO3)	≤ 300	120	100	160	130

Keys: EC: Electrical conductivity, TDS: Total Dissolved Solid, NTU: Nephelometric Turbidity Units, TH: Total Hardness.

Table 2 presents the microbial counts of borehole water samples from four hostels at Madonna University compared against WHO standards. Total heterotrophic bacterial counts (THBC) across all sites significantly exceed the WHO guideline of less than 100 CFU/mL, ranging from 1.2×10^2 in Miami to a high of 8.5×10^3 CFU/mL in Anthony Hostel, indicating substantial bacterial contamination. Total coliform (TC) and fecal coliform (FC) counts, which should ideally be zero according to WHO, were detected in all samples, with Anthony Hostel recording the highest contamination levels (15 MPN/100 mL for TC and 7 MPN/100 mL for FC). These findings highlight a critical microbial safety concern, rendering the borehole water microbiologically unsafe for direct consumption.

Table 2: Microbial Count obtained from Borehole water from selected hostels at Madonna University Elele, Rivers State, Nigeria.

Microbial Parameters	WHO Standard	St. Peter's	Miami	Anthony	Madonna
THBC(CFU/mL)	≤ 100CFU/mL	$1.5x10^3$	1.2×10^2	8.5×10^3	2.1×10^3
TC(MPN/100mL)	0MPN/100mL	6	3	15	4
FC(MPN/100mL)	NIL	2	0	7	1

Keys: THBC: Heterotrophic Bacteria Count, TC: Total Coliform, FC: Fecal Coliform

Table 3: details the antibiotic susceptibility patterns of bacterial isolates recovered from borehole water at Madonna University across four hostels. The isolates exhibit widespread multidrug resistance (MDR), particularly to ampicillin (AMP), tetracycline (TET), and ceftriaxone (CRO). Ciprofloxacin (CIP) showed consistent susceptibility across all isolates, with inhibition zones ranging from 25 to 30 mm, indicating retained effectiveness. Gentamicin (GEN) demonstrated variable efficacy, with most isolates susceptible or intermediately susceptible. Notably, *Escherichia coli* and *Pseudomonas aeruginosa* isolates from St. Peter and Anthony Hostels showed resistance to multiple antibiotics, underscoring a critical public health concern. Similarly, *Klebsiella pneumoniae* and *Enterobacter cloacae* isolates from Miami and Madonna Hostels displayed resistance to

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AMP and CRO, further confirming the prevalence of MDR pathogens in the water sources. These resistance profiles highlight the urgent need for monitoring and intervention to mitigate antimicrobial resistance dissemination in the environment.

Table 3: Antibiotic Susceptibility Profile of Bacterial Isolates by Location Obtained from Borehole Water at Madonna University, Elele, Rivers State, Nigeria.

Locations	Bacterial Isolates	AMP(10 µg)	CIP (5 µg)	GEN (10 µg)	TET (30 µg)	CRO(30µg)	Resistance Profile
St. Peter Hostel	*E. coli*	8mm(R)	28mm(S)	21mm(S)	11mm(R)	16mm(I)	AMP, TET(MDR)
	P. aeruginosa	10mm(R)	25mm(S)	19mm(S)	12mm(R)	14mm(R)	AMP, TET, CRO (MDR)
Miami Hostel	*K. pneumoniae*	9mm(R)	26mm(S)	22mm(S)	15mm(I)	13mm(R)	AMP, CRO (MDR)
	E. cloacae	13mm(R)	27mm(S)	20mm(S)	14mm(I)	18mm(S)	
Anthony Hostel	*E. coli*	7mm(R)	29mm(S)	16mm(I)	10mm(R)	12mm(R)	AMP,TET,CRO (MDR)
	S. aureus	9mm(R)	30mm(S)	23mm(S)	13mm(R)	20mm(S)	AMP, TET (MDR)
Madonna Hostel	*K. pneumoniae*	10mm(R)	26mm(S)	21mm(S)	15mm(I)	13mm(R)	AMP-CRO (MDR)
	P. aeruginosa	8mm(R)	25mm(S)	17mm(S)	11mm(R)	15mm(I)	AMP, TET (MDR)

Keys: MDR= Multi drug resistance, AMP=Ampicillin, TET=Tetracycline, CRO=Ceftriaxone, CIP=Ciprofloxacin, GEN=Gentamycin. Clinical and Laboratory Standard Institute (CLSI) Guidelines 2024, 33rd Edition= Sensitive (S): Zone diameter ≥ 17 mm, Intermediate (I): Zone diameter 14-16 mm Resistant (R): Zone diameter ≤ 13 mm.

4. DISCUSSION

4.1: Physicochemical Characteristics of Borehole Water

The physicochemical assessment of borehole water samples collected from four residential hostels St. Peters, Miami, Anthony, and Madonna at Madonna University, Elele, reveals overall compliance with the World Health Organization (WHO, 2017) guidelines for potable water, indicating that the groundwater sources are chemically suitable for domestic consumption. Nevertheless, spatial variations in certain parameters were evident, likely influenced by subsurface geological heterogeneity, disparities in borehole construction standards, and differential maintenance practices.

4.1.1: pH and Temperature

The measured pH values ranged from 6.5 to 7.4, comfortably within the WHO-recommended bracket of 6.5–8.5, suggesting that the water is mildly acidic to neutral—a pH range that minimizes corrosion in distribution systems and metal leaching into the water supply (WHO, 2017; Chapman, 1996). Temperature values, spanning 26.9°C to 28.1°C, are characteristic of groundwater from tropical climates. While WHO does not stipulate a maximum threshold for temperature, elevated thermal conditions may promote microbial proliferation, compromise palatability, and reduce consumer acceptance (Kumar et al., 2010).

4.1.2: Electrical Conductivity and Total Dissolved Solids

Electrical conductivity (EC) values across all samples remained between 180 and 320 µS/cm well beneath the WHO upper limit of 400 µS/cm reflecting low ionic strength and negligible anthropogenic contamination. Concurrently, Total Dissolved Solids (TDS) values ranged from 120 to 210 mg/L, significantly below the permissible limit of 500 mg/L, thereby affirming the chemical integrity and potability of the water. The strong positive correlation between EC and TDS further substantiates the assertion of low mineralization and absence of saline or industrial intrusion (Sawyer et al., 2003).

4.1.3: Turbidity

Turbidity levels recorded from 0.8 to 1.5 NTU fall substantially below the WHO guideline of 5 NTU, indicating high water clarity. Such low turbidity not only enhances aesthetic quality but also improves the efficacy of disinfection and reduces microbial harboring, as suspended solids are minimized (LeChevallier & Au, 2004). The clarity observed suggests sound borehole construction, particularly effective casing and gravel packing, which mitigate sediment ingress.

4.1.4: Nitrate and Chloride Concentrations

Nitrate levels varied from 3.8 to 6.2 mg/L, far below the critical threshold of 50 mg/L, thus posing negligible risk for nitrate-induced pathologies such as infantile methemoglobinemia. Chloride concentrations, spanning 35 to 58 mg/L, were similarly within acceptable limits, reflecting an absence of saline intrusion or sewage-related contamination. These levels ensure the water remains organoleptically acceptable and non-corrosive (Bartram & Balance, 1996).

4.1.5: Total Hardness

Total hardness, expressed as $CaCO_3$, ranged from 100 to 160 mg/L, classifying the water as

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moderately hard. This level of hardness is generally advantageous, contributing essential minerals such as calcium and magnesium to the human diet and offering some protection against pipe corrosion (U.S. EPA, 2009; Sengupta, 2013). Moderately hard water is also preferred for domestic applications such as washing and cooking due to its balanced taste and reduced soap consumption.

Therefore, the chemical attributes of the borehole water reflect a high degree of potability and require no immediate chemical treatment. However, this chemical safety is overshadowed by the microbial quality findings, which underscore a significant public health risk.

4.2: Microbiological Quality and Public Health Implications

The microbiological evaluation of borehole water samples from Madonna University revealed extensive bacterial contamination across all surveyed hostels, highlighting critical lapses in microbial safety. These findings directly contravene the WHO (2017) standards, which stipulate zero tolerance for coliforms and fecal indicator organisms in potable water.

4.2.1: Total Heterotrophic Bacterial Count (THBC)

THBC levels ranged between 1.2×10^2 and 8.5×10^3 CFU/mL dramatically exceeding the WHO guideline of 100 CFU/mL. The highest bacterial load was observed in Anthony Hostel, potentially indicative of elevated organic input, post-construction contamination, or biofilm development within the borehole infrastructure (LeChevallier et al., 1996). Such elevated heterotrophic counts signal diminished water quality and increased risk for opportunistic infections, particularly among immunocompromised populations.

4.2.2: Coliforms and Fecal Contamination

All water samples tested positive for total coliforms (1–15 MPN/100 mL) and fecal coliforms (0–7 MPN/100 mL), far surpassing the WHO permissible limit of 0 MPN/100 mL. The detection of *Escherichia coli* in samples from St. Peters and Anthony Hostels provides irrefutable evidence of fecal intrusion, possibly due to latrine seepage, defective borehole linings, or surface runoff infiltration (Edberg et al., 2000).

4.2.3: Presence of Opportunistic and Pathogenic Bacteria

The identification of *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, and *Enterobacter cloacae* in various samples is particularly alarming, given their association with nosocomial infections and antimicrobial resistance. *P. aeruginosa*, isolated from St. Peters and Madonna Hostels, is notoriously resilient due to its intrinsic resistance mechanisms and ability to persist in moist environments (Mena & Gerba, 2009).

The presence of such pathogenic taxa is consistent with prior studies across Nigeria and sub-Saharan Africa, which have documented the vulnerability of groundwater sources to microbial ingress, even in ostensibly protected boreholes (Chigor et al., 2012; Olaniran et al., 2013). These results render the borehole water categorically unsafe for human consumption without adequate disinfection measures, such as chlorination, ultraviolet treatment, or point-of-use filtration systems. The findings warrant the urgent implementation of routine microbial surveillance, infrastructural upgrades, and public education initiatives aimed at promoting hygienic water handling practices.

4.3: Antimicrobial Resistance Profile of Waterborne Isolates

The antimicrobial susceptibility profiles of bacterial isolates from borehole water samples revealed a disturbing prevalence of multidrug resistance (MDR), further complicating the public health landscape. All samples contained at least one isolate resistant to two or more antibiotic classes a hallmark of MDR pathogens.

4.3.1: Resistance Patterns and Clinical Implications

Universal resistance to ampicillin was observed across all isolates, reflecting the pervasive ineffectiveness of β-lactam antibiotics in the environment. Noteworthy resistance to tetracycline and ceftriaxone was also evident, particularly among *Pseudomonas aeruginosa* and *Escherichia coli* strains. These resistance patterns are indicative of extended-spectrum β-lactamase (ESBL) production, which limits therapeutic options and facilitates horizontal gene transfer (Livermore, 2004; Poole, 2011).

Notably, *E. coli* isolates from St. Peters and Anthony Hostels exhibited resistance to ampicillin, tetracycline, and ceftriaxone mirroring resistance profiles observed in healthcare settings. Similarly, *P. aeruginosa* isolates from Madonna and St. Peters Hostels demonstrated multidrug resistance, consistent with its well-documented arsenal of efflux pumps, porin mutations, and biofilm-mediated protection.

Despite the broad resistance landscape, ciprofloxacin exhibited 100% efficacy against all tested isolates, while gentamicin demonstrated substantial antimicrobial activity, with only two isolates showing intermediate susceptibility. These findings align with existing literature, which underscores the retained effectiveness of fluoroquinolones and aminoglycosides in contexts with relatively lower misuse (Ogbolu et al., 2011).

4.3.2: Public Health Significance

The detection of MDR organisms in borehole water designated for domestic use challenges conventional assumptions about groundwater safety and highlights systemic vulnerabilities in borehole construction, location, and post-extraction water

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handling. Moreover, the emergence of resistance in environmental *Staphylococcus aureus* isolates from Anthony Hostel signals potential zoonotic and community-acquired risks.
These trends are increasingly attributed to indiscriminate antibiotic use, environmental discharge of pharmaceutical residues, and inadequate wastewater treatment factors that collectively drive the propagation of resistance genes in aquatic environments (Okeke et al., 2005; WHO, 2020). The WHO's One Health framework emphasizes the integration of environmental surveillance into antimicrobial resistance mitigation strategies, a recommendation underscored by this study's findings.

5. CONCLUSION

The confluence of excellent physicochemical quality and alarming microbiological contamination in borehole water samples from Madonna University necessitates a dual-action approach to water safety. While chemical potability is assured, the microbial burden, including the prevalence of MDR organisms, renders the water unsuitable for direct consumption.

6. RECOMMENDATIONS

Immediate interventions are essential and should include:

i) Comprehensive water treatment strategies at the point of use;
ii) Routine microbiological and AMR surveillance;
iii) Enforcement of sanitary borehole construction standards;
iv) Community education on safe water practices; and
v) National antibiotic stewardship programs to mitigate environmental AMR propagation.

Note: Failure to act swiftly may exacerbate waterborne disease outbreaks and contribute significantly to the global antimicrobial resistance crisis a threat that increasingly transcends borders and disciplines.

7. CONTRIBUTIONS TO KNOWLEDGE

This study provides critical insights into the complex interplay between physicochemical suitability and microbiological hazards in borehole water sources within a sub-Saharan African university setting. It confirms that while groundwater can meet stringent WHO chemical standards for potability, microbiological contamination remains a pervasive and underestimated public health threat.
By systematically documenting spatial variations in water quality parameters, the research highlights the influence of geological heterogeneity and infrastructural integrity on groundwater chemistry, reinforcing the importance of rigorous borehole construction and maintenance practices. Importantly, the detection of fecal indicator bacteria and opportunistic pathogens coupled with the identification of multidrug-resistant (MDR) strains challenges prevailing assumptions of groundwater safety and underscores its vulnerability to contamination even in protected environments.
This investigation significantly advances knowledge on the environmental reservoirs of antimicrobial resistance (AMR), revealing the presence of extended-spectrum β-lactamase-producing bacteria and multidrug-resistant pathogens in community water supplies. These findings emphasize the urgent need to integrate microbial quality monitoring and AMR surveillance into water safety management, consistent with the WHO's One Health approach.
Collectively, the study offers a robust interdisciplinary framework that informs water resource management, public health policy, and antimicrobial stewardship in low- and middle-income countries, contributing to global efforts toward sustainable water security and the containment of antimicrobial resistance.

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