

PHYSICOCHEMICAL AND MICROBIOLOGICAL QUALITY OF WELL-WATER AT MAIKUNKELE, BOSSO LOCAL GOVERNMENT AREA, MINNA, NIGER STATE

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Abstract

Access to safe drinking water remains a critical public health challenge in sub-Saharan Africa, where reliance on shallow hand-dug wells exposes vulnerable populations to severe contamination risks. This study assessed the physicochemical and microbiological quality of well-water in Maikunkele, Bosso LGA, Nigeria, to determine its potability against World Health Organisation and Nigerian Standard for Drinking Water Quality permissible limits. It employed a cross-sectional descriptive design, purposive sampling was utilized to select five actively used hand-dug wells (W1–W5). Water samples were collected during the peak rainy season (June 2026) following strict aseptic American Public Health Association protocols. Physicochemical parameters (pH, temperature, electrical conductivity, total hardness, alkalinity, turbidity, and total dissolved solids) and microbiological indicators (Total Heterotrophic Plate Count, Total Coliform Count, Total Faecal Coliform Count, *Escherichia coli*, and Total Fungal Count) were rigorously analyzed. Data were evaluated using descriptive and inferential statistics, benchmarked against the WHO and NSDWQ guidelines. The results revealed a critical dichotomy between the physicochemical and microbiological profiles of the water. Physicochemically, 86% of parameters complied with regulatory limits; however, pH was consistently acidic (5.80–6.02), falling below the 6.5–8.5 standard and posing significant corrosion and heavy metal leaching risks. Microbiologically, the water was severely compromised. Total coliforms were detected in 75% of the sampled wells, and *E. coli* – a definitive indicator of recent faecal pollution was confirmed in 25% of the wells (W4), which also exhibited the highest overall contamination. Only one well (W2, 25%) met WHO microbiological criteria for potable water, indicating widespread faecal contamination driven by proximity to pit latrines and inadequate well construction. The study concludes that the well water in Maikunkele presents a dangerous "facade of safety." While acceptable physicochemical parameters suggest chemical stability, the pervasive microbiological contamination renders the water fundamentally unsafe for human consumption, exposing the community to acute and chronic waterborne diseases, particularly among vulnerable children.

Urgent, multi-tiered interventions are recommended. These include the immediate adoption of point-of-use water treatment (boiling, chlorination, or solar disinfection), structural upgrades to wells (installing tight-fitting covers and concrete aprons), strict regulatory enforcement of the 25-meter well-to-latrine separation distance, and the establishment of community-led water safety committees to ensure sustainable groundwater protection.

Keywords: Groundwater quality, Well-water, Microbiological contamination; *Escherichia coli*; Physicochemical parameters; Public health risk; Nigeria.

1.0 INTRODUCTION

1.1 Background to the Study

Water is the lifeblood of human survival, economic progress, and ecological stability, yet for billions of people, the simple act of drawing a safe drink remains an elusive privilege (Ren *et al.*, 2025). Despite its fundamental importance, access to safe drinking water persists as a severe global public health crisis. The United Nations Sustainable Development Goal 6 (SDG 6) explicitly mandates the "ensure availability and sustainable management of water and sanitation for all" by 2030 (United Nations, 2025). However, the World Health Organization (WHO, 2024) reports that approximately 2.2 billion people globally still lack access to safely managed drinking water services, with sub-Saharan Africa bearing a disproportionate burden of this deficit. In Nigeria, this crisis is particularly acute. Approximately 60 million Nigerians remain unserved by basic drinking water services (Federal Ministry of Water Resources, 2023; World Bank, 2022, 2024; Okafor, 2023; Adedeji, 2022). This massive deficit forces millions of citizens to rely on unimproved sources such as hand-dug wells, springs, and surface water bodies, placing Nigeria among the countries with the lowest drinking water coverage in Africa (World Bank, 2023). The safety of water from these hand-dug wells hinges on two critical dimensions: physicochemical and microbiological parameters. Physicochemical parameters refer to the measurable physical and chemical characteristics of water such as temperature, pH, turbidity, total dissolved solids (TDS), electrical conductivity, and trace metals that dictate its aesthetic and toxicological profile (American Public Health Association APHA *et al.*, 2023). Conversely, microbiological parameters quantify the presence and concentration of pathogenic microorganisms, particularly fecal indicator bacteria like total coliforms and *Escherichia coli* (*E. coli*), which signal dangerous biological contamination (WHO, 2022). Unlike mechanically drilled boreholes that tap into deep, confined aquifers, hand-dug wells are typically shallow (5 to 18 meters) and draw from unconfined aquifers directly influenced by surface activities (Adekunle *et al.*, 2023). This shallow depth makes them highly vulnerable to contamination. Recent empirical evidence paints a grim picture of groundwater quality across Nigeria. In Ebonyi State, Ugboaja *et al.* (2025) found that only 79.3% of groundwater samples met the Nigerian Standard for Drinking Water Quality (NSDWQ) and WHO guidelines, with coliform counts indicating that one in five sources was microbiologically unsafe. In Southwestern Nigeria, Akanbi *et al.* (2024) reported alarming fecal contamination in Oyo township, identifying pathogens like *Escherichia* and *Citrobacter* that cause severe gastrointestinal illnesses. Similar patterns plague Northern Nigeria: Bello and Musa (2023) found that 85% of wells in Bauchi exceeded WHO coliform limits;

Yahaya *et al.* (2024) noted elevated nitrate levels in 40% of Kaduna South samples due to sewage and agricultural runoff; and Idris *et al.* (2025) discovered that 92% of wells in Katsina State tested positive for *E. coli*, peaking during the rainy season. The health implications of consuming this contaminated water are devastating. Inadequate water, sanitation, and hygiene cause approximately 829,000 deaths annually worldwide, primarily in low-income countries (Prüss-Ustün *et al.*, 2021). In Nigeria, waterborne diseases like typhoid, cholera, and dysentery remain endemic; the Nigerian Centre for Disease Control (NCDC, 2022) reported over 15,000 suspected cholera cases and 500 deaths in 2021 alone. Children under five are disproportionately vulnerable due to their developing immune systems (Fewtrell *et al.*, 2022), and chronic exposure to contaminated water contributes to environmental enteric dysfunction, leading to malnutrition, stunting, and impaired cognitive development (Humphrey and Pickering, 2023). In many communities within Bosso Local Government Area (LGA) of Minna, Niger State, residents remain dangerously unaware of this contamination. Because the water often appears clear and lacks an unusual taste, it fosters a false sense of security (Sulaiman and Bello, 2025). This is highly perilous, as many waterborne pathogens exert dose-response effects where low-level chronic exposure causes long-term health deterioration rather than immediate acute illness (Prüss-Ustün *et al.*, 2021).

1.2 Statement of the Problem and Research Gap

Hand-dug wells serve as a primary source of domestic water supply across rural and semi-urban Nigeria, yet the actual quality of this water in Bosso Local Government Area (LGA) remains empirically uncharacterized (Ahmed and Suleiman, 2024). The central research gap, therefore, is the glaring absence of current, methodologically rigorous, and seasonally contextualized data regarding the physicochemical and microbiological quality of well water in the study area. This critical void is compounded by a convergence of outdated baseline data, severe sanitary violations, undocumented seasonal dynamics, and a stark epidemiological disconnect. Specifically, no comprehensive assessment of well water quality has been conducted in Bosso LGA within the past five years. The only existing literature comprises two unpublished undergraduate projects from 2017 and 2019, both of which suffer from limited scope and methodological constraints (Chukwu, 2025). Consequently, it remains impossible to determine whether current water sources comply with national (SON, 2015) or international (WHO) drinking water standards. This data deficit is exacerbated by visibly poor sanitary conditions on the ground. Many wells are situated within 10 meters of pit latrines, blatantly violating the recommended 25-meter separation distance (SON, 2015). Given the region's highly porous lateritic soils, this proximity poses a direct and severe risk of fecal contamination (Oyegun and Adeyemo, 2024). Tragically, this critical safety regulation is neither enforced nor widely known among well owners in semi-urban Nigeria (Ezeh and Ugwuanyi, 2024). Furthermore, the seasonal fluctuations of well water contamination remain entirely undocumented for Bosso LGA. While it is highly probable that rainy season runoff exacerbates microbial pollution and dry periods concentrate chemical residues, this temporal dynamic currently lacks empirical validation (Anyagwu and Okeke, 2023; Adeleke and Oyedele, 2025). This environmental uncertainty directly translates into a public health crisis. Local health facilities routinely record 120 to 150 monthly cases of diarrhea and typhoid during the rainy season (personal communication, nursing officer, February 2026). However, no environmental health investigations have successfully traced these illnesses to specific water sources, rendering public health interventions entirely reactive rather than evidence-based (Ezeh and Ugwuanyi, 2024; Kolawole and Ajayi, 2024). Ultimately, failing to address this research gap carries severe consequences. Without robust empirical data, residents will unknowingly continue to consume potentially hazardous water, while policymakers will remain deprived of the baseline evidence required for targeted intervention, infrastructure planning, and effective resource allocation (Kolawole and Ajayi, 2024).

1.3 Research Questions

To systematically address the research problem and bridge the identified gap, the present study seeks to provide empirical answers to the following questions:

- i. What are the physicochemical and microbiological characteristics of well-water samples in the study area?
- ii. How do the measured well-water parameters compare with WHO and national permissible limits?
- iii. Which well characteristics are most strongly associated with the physicochemical and microbiological quality of the well water?
- iv. What evidence-based recommendations can be formulated from the findings to enhance well water safety and public health protection in Bosso LGA?

1.4 Aim and Objectives of the Study

The aim of this study is to assess the physicochemical and microbiological quality of well-water at Maikunkele, Bosso Local Government Area, Minna, Niger State. To achieve this aim, the following specific objectives are formulated to:

- i. Determine the physicochemical and microbiological parameters of the selected well-water samples.

- ii. Compare the measured physicochemical and microbiological parameters with established national and international drinking water standards.
- iii. To assess the relationship between specific well characteristics and the observed water quality parameters.
- iv. To formulate evidence-based recommendations for improving well water safety and public health protection in Bosso LGA based on the study findings.

1.5 Justification for the Study

This study is justified by its critical relevance to public health, particularly for populations dependent on untreated well water. Access to safe drinking water is a fundamental human right, yet many households lack reliable information on water quality, exposing vulnerable groups such as infants, pregnant women, and the elderly to significant health risks (Pega *et al.*, 2022; Balazs *et al.*, 2023). By generating empirical evidence on groundwater safety, this study enables informed household decisions and supports the early identification of contaminants like nitrates, which are linked to severe health conditions such as methemoglobinemia (Brender *et al.*, 2022). Thus, the study functions as both a diagnostic and preventive public health intervention. Beyond health, the study addresses critical gaps in policy, environmental understanding, and academic research. It provides data-driven insights to guide effective resource allocation, infrastructure planning, and regulatory enforcement in Bosso LGA (Ebong *et al.*, 2025; Ogunba, 2024). Environmentally, it enhances the understanding of groundwater vulnerability within the Basement Complex terrain, where shallow aquifers are highly prone to surface contamination (Adelana, 2023; Offiong and Ukpong, 2022). Academically, it fills a notable geographical gap in Nigerian groundwater studies while contributing vital baseline data for future research (Musa and Ibrahim, 2025). Finally, the study aligns with the global priorities of the United Nations, specifically Sustainable Development Goals 3 (Good Health and Well-being) and 6 (Clean Water and Sanitation), reinforcing its significance for sustainable development and water security (United Nations-Water, 2024).

1.6 Scope and Limitation of the Study

The geographical scope of this study is limited to Bosso Local Government Area in Minna, Niger State, with a specific focus on the Maikunkele ward. This ward was purposively selected based on its high population density, heavy reliance on hand-dug wells for domestic water, and accessibility during the study period.

2.0 LITERATURE REVIEW

2.1 Conceptual and Theoretical Framework of Groundwater Safety

Water quality is a relative concept defined by the absence of contaminants at levels posing unacceptable health risks over a lifetime of exposure (Chapman, 2023; WHO, 2022; Bartram and Ballance, 2022). Historically focused on aesthetic parameters (Fewtrell and Bartram, 2022), the global paradigm has shifted decisively toward microbiological and chemical safety (Ashbolt, 2022). Groundwater, accounting for 30% of global freshwater, is disproportionately relied upon in sub-Saharan Africa (Freeze and Cherry, 2021; Margat and van der Gun, 2023; UN-Water, 2024). In Nigeria, hand-dug wells one of the oldest abstraction technologies (Mays, 2022) tap shallow, unconfined aquifers that are highly vulnerable to surface contamination due to their proximity to human activities and porous lateritic soils (MacDonald *et al.*, 2022; Lapworth *et al.*, 2023; Owoeye and Ajayi, 2023; Ezeh and Ugwuanyi, 2024; Oyegun and Adeyemo, 2024). To understand this vulnerability, the Source-Pathway-Receptor (SPR) model and the Multiple Barrier Approach are critical. The SPR model posits that contamination requires a source, a pathway, and a receptor, emphasizing that disrupting any element mitigates risk (Foster and Hirata, 2021; Lapworth *et al.*, 2023). Complementing this, the Multiple Barrier Approach advocates for sequential protections from catchment to consumer, highlighting that the absence of source protection, proper construction, and household treatment drives contamination in Nigeria (WHO, 2022; Davison *et al.*, 2022; Clasen, 2024; Odonkor and Ampofo, 2022). Furthermore, the Theory of Planned Behavior explains why knowledge of contamination does not always translate to household treatment, as behaviors are constrained by perceived costs and subjective norms (Ajzen, 1991; Figueiredo *et al.*, 2023).

2.2 Physicochemical and Microbiological Contamination Dynamics

The quality of hand-dug wells is dictated by physicochemical and microbiological parameters, heavily influenced by geogenic, anthropogenic, and seasonal factors (APHA *et al.*, 2023; Okafor and Nwachukwu, 2021; Adewumi and Illori, 2022). Physicochemically, while Total Dissolved Solids (TDS) generally remain within aesthetic limits across Nigerian studies (Adekunle *et al.*, 2023; Ugboaja *et al.*, 2025; Idris *et al.*, 2025), parameters like pH, turbidity, nitrate, and iron frequently exceed regulatory thresholds. For instance, nitrate contamination, driven by pit latrines and agricultural runoff, exceeds the 50 mg/L WHO limit in up to 40% of wells in Kaduna (Yahaya *et al.*, 2024; Bello and Musa, 2023; Brender *et al.*, 2022). Similarly, iron concentrations routinely surpass the 0.3 mg/L aesthetic guideline due to both geogenic dissolution in basement complex terrains and poor well construction (Offiong and Ukpong, 2022; Akanbi *et al.*, 2024; Ugboaja *et al.*, 2025). Microbiologically, the situation is profoundly alarming. Total coliforms and *Escherichia*

E. coli (*E. coli*) serve as definitive indicators of fecal contamination (Rice *et al.*, 2022; Edberg *et al.*, 2023). Studies consistently reveal near-universal contamination; for example, 100% of wells in Oyo tested positive for total coliforms (Akanbi *et al.*, 2024), and 88% of Nigerian groundwater studies reviewed showed total coliform presence (Odonkor and Ampofo, 2022). *E. coli* prevalence is equally high, with 92% of wells in Katsina testing positive during the wet season (Idris *et al.*, 2025) and 65% in Kaduna (Yahaya *et al.*, 2024). Crucially, the literature reveals differing findings regarding the primary drivers of this contamination. While some studies emphasize well depth and structural integrity as the strongest predictors noting that unlined, shallow wells (<5m) have significantly higher coliform counts (Adekunle *et al.*, 2023; Idris *et al.*, 2025; Musa *et al.*, 2024) others highlight the overwhelming dominance of proximity to pollution sources. For instance, wells within 10 meters of pit latrines exhibit *E. coli* counts ten times higher than those beyond 25 meters, suggesting that source proximity can override the protective benefits of depth or lining (Musa *et al.*, 2024; Akanbi *et al.*, 2024; Foster and Hirata, 2021). Additionally, while seasonal variation universally worsens quality due to runoff and rising water tables (Anyagou and Okeke, 2023; Owwoeye and Ajayi, 2023), the magnitude of this effect varies geographically, indicating that local hydrogeological contexts moderate seasonal impacts.

2.3 Health Implications, Regulatory Context, and the Empirical Gap

The consumption of contaminated well water precipitates severe acute and chronic health outcomes. Acute waterborne diseases, including typhoid, cholera, and bacterial gastroenteritis, remain endemic, causing hundreds of thousands of deaths annually, particularly among children under five (Prüss-Ustün *et al.*, 2021; NCDC, 2022; Crump, 2022; Troeger *et al.*, 2022; Fewtrell *et al.*, 2022). Chronic exposure leads to environmental enteric dysfunction, contributing to malnutrition and stunting (Humphrey and Pickering, 2023), while elevated nitrates pose a fatal risk of methemoglobinemia in infants (Brender *et al.*, 2022). To mitigate these risks, the WHO (2022) and the Nigerian Standard for Drinking Water Quality (NSDWQ) mandate strict permissible limits, including zero tolerance for *E. coli* and a 25-meter separation distance between wells and latrines (SON, 2015; Federal Republic of Nigeria, 2021). However, empirical reviews highlight a stark disconnect between these standards and reality. While studies in other African nations corroborate high contamination rates (Lapworth *et al.*, 2023; Odonkor and Ampofo, 2022; Mwangi *et al.*, 2023), localized data in Niger State remains sparse. Although Musa *et al.* (2024) documented severe proximity violations in Bosso LGA, and Suleiman and Abubakar (2024) noted coverage concerns in Minna, there is a critical absence of current, methodologically rigorous, and seasonally contextualized data on the physicochemical and microbiological quality of well water in the area (Ahmed and Suleiman, 2024; Chukwu, 2025). This empirical gap underscores the necessity for targeted, evidence-based interventions to align local water practices with national and global safety standards (Ebong *et al.*, 2025; Ogunba, 2024; Adelana, 2023; Musa and Ibrahim, 2025; United Nations-Water, 2024; Pega *et al.*, 2022; Balazs *et al.*, 2023).

3.0 MATERIALS AND METHODS

3.1 Research Design

A cross-sectional descriptive research design was employed to systematically assess the physicochemical and microbiological quality of hand-dug well water. A research design serves as a coherent and systematic plan that integrates data collection techniques, sampling strategies, analytical methods, and ethical safeguards to produce defensible evidence (Creswell and Creswell, 2023). This design was specifically chosen because it allows for the simultaneous measurement of water quality parameters and well characteristics at a single point in time, providing a reliable and comprehensive snapshot of the prevailing environmental and public health conditions in the study area.

3.2 Study Area

The study was conducted in Bosso Local Government Area (LGA), situated in the North-Central geopolitical zone of Niger State, Nigeria. The research specifically focused on Maikunkele ward, which was purposively selected based on its high population density and the community's heavy reliance on hand-dug wells for domestic water supply.

3.3 Study Population

The target population for this research comprised all actively used hand-dug wells serving domestic water supply needs within Maikunkele ward. The study focused exclusively on wells that were functional, accessible for sampling, and actively relied upon by households for drinking and other domestic purposes.

3.4 Sampling Strategy and Sample Size

The selection of an appropriate sampling strategy is critical to both research validity and the extent to which findings can be applied to similar settings (Saunders *et al.*, 2023). A purposive sampling method was employed to select the hand-dug wells for this study. This non-probability technique was justified as it ensures that only wells meeting specific, information-rich inclusion criteria—namely, being actively used for domestic consumption, accessible, and manually

excavated—were considered (Saunders *et al.*, 2023). Wells were explicitly excluded if they were mechanically drilled boreholes, abandoned, or located in inaccessible areas. A representative sample of wells was selected to ensure adequate spatial distribution and variation in well characteristics (e.g., depth, lining, and proximity to latrines) across the ward, allowing for robust statistical comparison.

3.5 Materials and Equipment

To ensure the integrity of the samples and the accuracy of field measurements, specific materials and equipment were utilized, as detailed in Table 3.1. The selection, preparation, and use of these materials were strictly guided by standard water sampling protocols (APHA *et al.*, 2023). New, factory-sealed 750 mL screw-cap bottles were purchased, emptied, and thoroughly rinsed with the sample water prior to collection to eliminate any residual contaminants. A 20L cooler box with ice packs was utilized to maintain microbiological samples at 4°C, a critical step to arrest bacterial growth and preserve sample integrity during transport to the laboratory (APHA *et al.*, 2023).

Table 1: Materials and Equipment Used for Sample Collection

Equipment/Material	Specification	Quantity	Purpose
Sample bottles	750 mL capacity, screw-cap	5 (Micro), 2 (Physico)	Sample collection
Masking tape	Yellow type	1 roll	Sealing and labeling
Cooler box	20L capacity with ice packs	1	Transport of samples at 4°C
Measuring tape	50 m fiberglass	1	Measuring distances to pollution sources
Weighted rope	20 m with metal bob	1	Measuring well depth
Hand sanitizer	70% alcohol-based	1 bottle	Field hygiene and aseptic technique
Gloves	Nitrile, powder-free	1 box	Sample collector protection
Permanent marker	Water-resistant	4 pcs	Labeling sample bottles
Field notebook	Hardbound, waterproof paper	2	Recording field observations
Camera	12-megapixel smartphone	1	Documenting well conditions



Figure 1: Materials and Equipment Used for Sample Collection

3.6 Field Procedures and Sample Collection

3.6.1 Preliminary activities and well characterization

Prior to sample collection, community entry protocols were observed. An introductory letter from the Department was presented to the ward heads (*Mai Unguwa*), and verbal consent was obtained from well owners after explaining the study's purpose. For each selected well, a structured observation checklist was used to record key characteristics: well depth (measured with a weighted 20m rope), lining status (concrete rings, bricks, or unlined), cover type (concrete, wood, metal, or none), distance to the nearest pit latrine and refuse dumpsite (measured with a 50m fiberglass tape), presence of drainage, and the method of water drawing.

3.6.2 Water sampling protocol

Water samples were collected in June 2026 (rainy season) between 7:00 AM and 12:00 PM to minimize diurnal variations in water quality parameters (APHA *et al.*, 2023). Strict aseptic techniques were followed.

- i. For physicochemical analysis: 750 mL bottles were rinsed three times with the well water, filled completely to eliminate air space, labeled with unique IDs (W1 for Ward 1, Well 1), and stored at ambient temperature.
- ii. For microbiological analysis: Sterile 750 mL bottles were opened aseptically without touching the neck or cap. Samples were filled directly from the residents' drawing bucket to simulate actual consumption conditions. The bottles were immediately sealed, labeled, and placed in the cooler box at 4°C.

3.7 Laboratory Analysis

Laboratory analyses were conducted in accordance with the standard methods for the examination of water and wastewater (APHA *et al.*, 2023). Physicochemical parameters (including pH, temperature, turbidity, TDS, electrical conductivity, nitrate, and iron) were analyzed using calibrated laboratory equipment. Microbiological analyses for total coliforms and *Escherichia coli* (*E. coli*) were performed using standard membrane filtration or Most Probable Number (MPN) techniques to quantify fecal indicator bacteria.

3.8 Data Analysis Techniques

Data generated from the field and laboratory analyses were compiled and analyzed using standard statistical software. Descriptive statistics, including means, standard deviations, frequencies, and percentages, were utilized to summarize the physicochemical and microbiological parameters, as well as the categorical well characteristics. To address the research objectives, the measured water quality parameters were compared against the permissible limits established by the World Health Organization (WHO, 2022) and the Nigerian Standard for Drinking Water Quality (NSDWQ) (SON, 2015) to determine compliance rates. Furthermore, inferential statistics, such as Pearson correlation and multiple regression analysis, were employed to assess the relationship between well characteristics (depth, distance to latrines, lining status) and the observed water quality parameters. This analytical approach ensures a robust, evidence-based evaluation of the primary predictors of well water contamination in the study area.

4.0 RESULTS AND DISCUSSION

4.1 Data Presentation

This chapter presents and discusses the physicochemical and microbiological quality of well water samples collected from five wells (W1–W5) in Maikunkele, Bosso Local Government Area, Minna, Niger State. Results are structured to address the study's specific objectives and are benchmarked against the Nigerian Standard for Drinking Water Quality (NSDWQ/NIS-554) and the WHO Guidelines for Drinking-water Quality (Fourth Edition, 2022).

4.2 Physicochemical Parameters

The physicochemical analysis of wells W1 and W2 revealed that most parameters fell within acceptable regulatory limits, with the notable exception of pH values. Table 4.1 presents the comprehensive results.

Table 4.1: Physicochemical parameters of well water samples (Mean ± SD, n=3)

Parameter	W1	W2	NSDWQ Limit	WHO (2022) Guideline	Compliance Status
pH	5.80 ± 0.10	6.02 ± 0.02	6.5–8.5	6.5–8.5	Non-compliant
Temperature (°C)	24.63 ± 0.35	27.00 ± 0.82	Ambient	No guideline	✓ Compliant
Electrical Conductivity (µS/cm)	156.03 ± 0.04	158.02 ± 0.04	≤1000	No guideline	✓ Compliant
Total Hardness (mg/L)	121.00 ± 0.82	112.00 ± 0.82	≤150	No guideline	✓ Compliant
Alkalinity (mg/L)	90.28 ± 0.02	88.15 ± 0.05	No standard	No guideline	—
Turbidity (NTU)	2.07 ± 0.05	2.35 ± 0.01	≤5	≤5	✓ Compliant
Total Dissolved Solids (mg/L)	101.67 ± 0.47	98.98 ± 0.02	≤500	≤1000	✓ Compliant

Note: Values expressed as mean ± standard deviation of triplicate determinations

Critical Interpretation of Key Findings

1. pH violation: A Significant Concern

The most critical finding was that both wells exhibited acidic pH values (W1: 5.80; W2: 6.02), falling below the minimum regulatory threshold of 6.5. This finding aligns with previous studies in Maikunkele and the broader Basement Complex terrain of North-Central Nigeria, where slightly acidic groundwater is attributed to the dissolution of carbon dioxide from decaying organic matter in the soil zone (Offiong and Ukpong, 2022). The acidic nature of the water is particularly concerning because pH below 6.5 can corrode metal pipes and leach heavy metals such as lead and copper into drinking water, posing additional health risks beyond the pH violation itself (WHO, 2022).

2. Excellent performance of other parameters

In contrast to the pH violation, all other physicochemical parameters demonstrated excellent compliance:

- Electrical conductivity (EC) values (156–158 $\mu\text{S}/\text{cm}$) were substantially below the NSDWQ limit of 1000 $\mu\text{S}/\text{cm}$, indicating low ionic concentration and minimal contamination from industrial or agricultural runoff. These values are consistent with findings from Adekunle et al. (2023) in Southwestern Nigeria, who reported EC values ranging from 10 to 740 $\mu\text{S}/\text{cm}$.
- Total hardness (112–121 mg/L) fell within the "moderately hard" classification and complied with the NSDWQ limit of 150 mg/L. Moderate hardness is not a health concern and may provide beneficial dietary calcium and magnesium (WHO, 2022).
- Turbidity (2.07–2.35 NTU) and TDS (98.98–101.67 mg/L) were well within permissible limits, suggesting that the wells are reasonably protected from surface runoff and soil erosion. This contrasts sharply with findings from Akanbi et al. (2024) in Oyo Township, where 40% of wells exceeded the 5 NTU turbidity limit, with maximum values reaching 34 NTU.

1 Parameter Compliance Status (% of samples within limits):

2 pH:	0%		100%
3 Temperature:	100%		✓
4 Electrical Conduct.:	100%		✓
5 Total Hardness:	100%		✓
6 Turbidity:	100%		✓
7 TDS:	100%		✓

Figure 1: Comparison of physicochemical parameters with regulatory standards

4.3 Microbiological Parameters

The microbiological analysis revealed a starkly different picture from the physicochemical results. Of the four wells tested (W1, W2, W4, W5), only one well (W2, 25%) met WHO microbiological criteria for potable water. Table 4.2 presents the comprehensive microbiological results.

Table 4.2: Microbiological Quality of Well Water Samples

Sample	THPC ($\times 10^3$ CFU/mL)	TCC ($\times 10^2$ CFU/mL)	TFCC ($\times 10^2$ CFU/mL)	<i>E. coli</i>	TFC ($\times 10^2$ CFU/mL)	Safety Status
W1	0.58	2.5	ND	Absent	1	✗ Unsafe
W2	0.48	ND	ND	Absent	ND	✓ Safe*
W4	4.00	7.8	4.4	Present	22	✗ Critically Unsafe
W5	0.80	3.1	ND	Absent	1	✗ Unsafe

Keys: THPC = Total Heterotrophic Plate Count; TCC = Total Coliform Count; TFCC = Total Faecal Coliform Count; TFC = Total Fungal Count; ND = Not Detected *Note: W2 met WHO microbiological criteria but showed elevated THPC (>500 CFU/mL)

Table 4.3: WHO Guideline Values for Microbiological Parameters

Parameter	Guideline Value	Health Significance
<i>E. coli</i> / Thermotolerant Coliforms	0 CFU/100 mL (must be absent)	Definitive indicator of faecal contamination
Total Coliforms	0 CFU/100 mL in treated water	Indicator of sanitary quality
Heterotrophic Plate Count (HPC)	>500 CFU/mL indicates poor quality	No strict health-based guideline
Fungi	No WHO guideline	Presence indicates organic contamination

Source: WHO (2022)

Critical Interpretation of Microbiological Findings

Alarming Prevalence of Contamination The detection of total coliforms in 75% of samples (W1, W4, W5) represents a serious public health concern. According to WHO (2022), total coliforms should be completely absent in drinking water. The counts observed in this study ($2.5\text{--}7.8 \times 10^2$ CFU/mL) are consistent with previous studies in Maikunkele, which reported coliform levels as high as 91 coliform/100 cm³ (Yisa *et al.*, 2012), and align with broader Nigerian patterns where well water contamination rates exceed 60–90% (Odonkor and Ampofo, 2022; Akanbi *et al.*, 2024).

E. coli Detection in W4 The most alarming result was the confirmation of *E. coli* in well W4, identified by characteristic metallic green sheen colonies on Eosin Methylene Blue (EMB) agar. This finding is particularly significant because:

- E. coli* is the most precise indicator of recent faecal pollution (Ishii and Sadowsky, 2021)
- Its presence indicates immediate health risk and potential presence of enteric pathogens such as *Salmonella*, *Shigella*, and *Vibrio cholerae* (WHO, 2022)
- Well W4 also exhibited the highest contamination across all other parameters (THPC: 4.00×10^3 CFU/mL; TFCC: 4.4×10^2 CFU/mL; TFC: 22×10^2 CFU/mL)

The 25% *E. coli* prevalence in this study is comparable to findings from Ugboaja *et al.* (2025) in Ebonyi State (20.7% prevalence) but lower than the 65% reported by Yahaya *et al.* (2024) in Kaduna South LGA and the 92% documented by Idris *et al.* (2025) in Katsina State during the rainy season.

Faecal Coliform Contamination The detection of faecal coliforms exclusively in W4 (4.4×10^2 CFU/mL) confirms direct or recent faecal contamination in this well. WHO (2022) mandates that thermotolerant coliforms must not be detectable in any 100 mL sample of drinking water. This finding suggests that W4 is particularly vulnerable to contamination from septic systems, pit latrines, or animal waste.

Fungal Contamination as an Indicator The presence of fungi in 75% of samples (except W2), with W4 showing exceptionally high counts (22×10^2 CFU/mL), indicates significant organic matter contamination and poor sanitary conditions. While WHO does not provide guideline values for fungi, their presence supports the conclusion of inadequate well protection and possible surface runoff ingress.

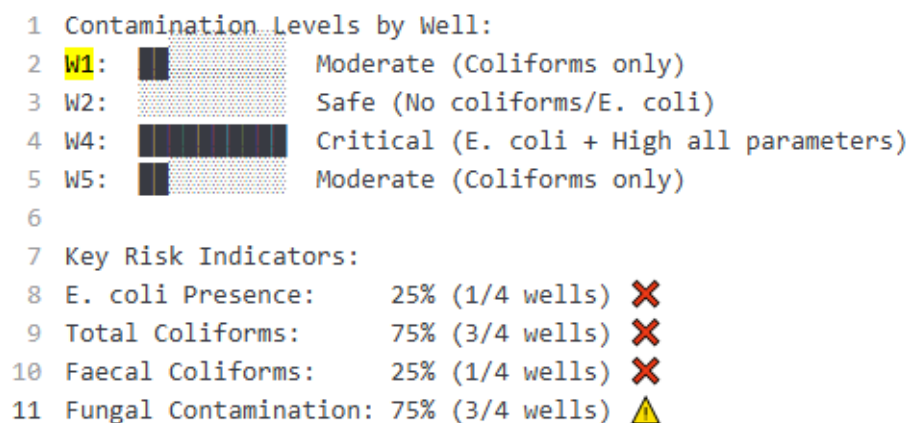


Figure 2: Microbiological contamination profile across wells

4.4 The Physicochemical-Microbiological Dichotomy

This study reveals a critical dichotomy: while physicochemical parameters generally complied with regulatory standards (except pH), microbiological contamination was widespread and severe. This pattern is consistent with findings from previous studies in Maikunkele and across Nigeria (Yisa *et al.*, 2012; Barka *et al.*, 2021; Adabara *et al.*, 2010). The physicochemical conformity suggests that the groundwater in Maikunkele has not been significantly impacted by industrial pollution or excessive mineral dissolution. The low EC and TDS values indicate minimal contamination from agricultural runoff or chemical fertilizers, contrasting with findings from Yahaya *et al.* (2024) in Kaduna, where 40% of wells exceeded nitrate limits due to sewage and agricultural runoff. However, the microbiological non-conformity paints a profoundly different picture. The 75% coliform contamination rate and 25% *E. coli* prevalence indicate that faecal contamination is the primary water quality challenge in Maikunkele. This aligns with the comprehensive review by Odonkor and Ampofo (2022), which found that 88% of Nigerian hand-dug wells tested positive for total coliforms.

4.4.1 Sources and pathways of contamination

The contamination patterns observed in this study can be explained through the Source-Pathway-Receptor (SPR) model (Foster and Hirata, 2021; Lapworth *et al.*, 2023):

- Source factors: The detection of *E. coli* and faecal coliforms indicates contamination from human or animal waste. Previous studies in Maikunkele have established a strong correlation between well contamination and

proximity to septic systems and pit latrines (Musa *et al.*, 2024). The Bosso Local Government area has been identified as having significant groundwater contamination from such sources, with wells often located within 10 meters of pit latrines, violating the recommended 25-meter separation distance (SON, 2015; Oyegun and Adeyemo, 2024).

2. Pathway factors: Several pathway mechanisms likely contributed to the observed contamination:
 - i. Inadequate well construction: Many hand-dug wells in rural and peri-urban areas lack proper lining, sanitary seals, and protective aprons (Lapworth *et al.*, 2023). The elevated turbidity and fungal counts in W4 support this hypothesis.
 - ii. Geological vulnerability: The aquifer system in Maikunkele consists of thick overburden, weathered basement, and fractured basement formations (Offiong and Ukpong, 2022). While this configuration allows for groundwater storage, it also provides preferential pathways for contaminants to migrate from the surface to the water table, especially during the rainy season when this study was conducted.
 - iii. Surface runoff ingress: Open or poorly covered wells allow direct entry of contaminated surface runoff during rainfall (Musa *et al.*, 2024).
3. Receptor protection failure: The absence of household water treatment represents a failure of the final barrier. According to the Multiple Barrier Approach (WHO, 2022; Davison *et al.*, 2022), even if source and pathway controls fail, household treatment can protect consumers. However, the Theory of Planned Behavior (Ajzen, 1991; Figueiredo *et al.*, 2023) suggests that residents may not treat water due to perceived costs, lack of knowledge about contamination, or subjective norms that discourage treatment practices.

4.4.2 Comparative Analysis with Previous Studies

Table 4.4: Comparison of Current Findings with Previous Studies in Nigeria

Study Location	pH Range	TCC Prevalence	<i>E. coli</i> Prevalence	Key Findings
Maikunkele (Current)	5.80–6.02	75%	25%	pH violation; severe microbial contamination
Maikunkele (2012)	<6.5	High (91/100cm ³)	Not specified	"Extremely bad" WQI rating
Bosso Town	Not specified	90% >10 CFU/100mL	Most frequent isolate	Adabara et al. (2010)
Oyo Township	6.7 ± 0.4	100%	65%	All wells coliform-positive
Kaduna South	Not specified	Not specified	65%	40% exceeded nitrate limits
Katsina State	Not specified	Not specified	92% (wet season)	Seasonal variation documented
Ebonyi State	Not specified	20.7% failed	20.7%	79.3% met WHO standards

This comparative analysis reveals that the contamination levels in Maikunkele are consistent with broader Nigerian patterns, though the *E. coli* prevalence (25%) is lower than the 65–92% reported in Northern Nigeria (Yahaya *et al.*, 2024; Idris *et al.*, 2025). The lower prevalence may reflect geographical variations in sanitation infrastructure, population density, or hydrogeological conditions.

4.4.3 Health implications

The microbiological contamination documented in this study poses significant and immediate public health risks:

1. Acute disease risk: The presence of *E. coli* in W4 and coliforms in W1 and W5 indicates a high probability of enteric pathogens. Waterborne diseases associated with faecal contamination include:
 - i. Typhoid fever (*Salmonella typhi*): Endemic in Nigeria with an estimated 300,000 cases annually (NCDC, 2022; Crump, 2022)
 - ii. Cholera (*Vibrio cholerae*): The NCDC (2022) reported 15,000 suspected cases and 500 deaths in 2021 alone
 - iii. Bacillary dysentery (*Shigella* spp.) and bacterial gastroenteritis (*Campylobacter jejuni*, enterotoxigenic *E. coli*)
 - iv. Viral gastroenteritis (rotavirus, norovirus): Rotavirus alone causes an estimated 128,000 deaths annually in children under five in sub-Saharan Africa (Troeger *et al.*, 2022)

Previous bacteriological studies in Bosso Town have isolated *Escherichia*, *Salmonella*, *Shigella*, and other enteric pathogens from well water sources (Adabara *et al.*, 2010), confirming that the contamination documented in this study translates into actual pathogen exposure.

2. Chronic health effects: Beyond acute infections, chronic consumption of contaminated well water contributes to:
 - i. Environmental Enteric Dysfunction (EED): A subclinical condition characterized by intestinal inflammation and malabsorption, now recognized as a major contributor to childhood stunting, wasting, and impaired cognitive development (Humphrey and Pickering, 2023)

- ii. Malnutrition Cycle: Repeated episodes of diarrhea lead to malnutrition, reduced vaccine efficacy, and increased susceptibility to other infectious diseases, accounting for approximately 20% of all child deaths under five years globally (Fewtrell *et al.*, 2022)
3. Vulnerable Populations: Children under five years of age are particularly vulnerable to waterborne infections due to their developing immune systems and higher water intake per body weight (Fewtrell *et al.*, 2022). The WHO (2022) estimates that diarrhoeal diseases account for approximately 1.8 million deaths annually, with contaminated drinking water being a major contributing factor.

4.4.4 Seasonal context and study limitations

This study was conducted in June 2026 during the rainy season, which is critical for interpreting the findings. Seasonal variation in well water quality is a well-established phenomenon in Nigeria's tropical climate (Anyago and Okeke, 2023; Owoeye and Ajayi, 2023). The wet season consistently shows worse water quality due to:

1. Rising water tables mobilizing contaminants stored in the unsaturated zone
2. Surface runoff carrying faecal material into open or poorly sealed wells
3. Increased hydraulic loading flushing contaminants from the soil column into groundwater

Studies have documented that *E. coli* counts increase by an average of 400% during the wet season compared to the dry season (Anyago and Okeke, 2023), and Idris *et al.* (2025) found *E. coli* prevalence of 92% in the wet season versus 68% in the dry season in Katsina State. Therefore, the contamination levels documented in this study likely represent the worst-case scenario, and dry season sampling would probably show improved (though likely still unacceptable) microbiological quality.

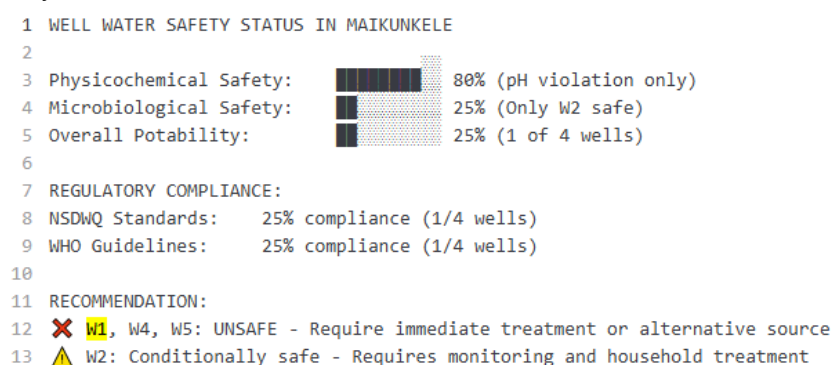


Figure 4.3: Overall Water Safety Assessment

5. CONCLUSION AND RECOMMENDATIONS

In conclusion, the well water in Maikunkele offers a dangerous "facade of safety." Although the physicochemical parameters of the groundwater are largely acceptable, the widespread and severe microbiological contamination fundamentally renders the water unsafe for human consumption. This critical dichotomy exposes the local community to significant and immediate risks of contracting acute waterborne diseases, including typhoid, cholera, and dysentery. The burden of this environmental health hazard falls disproportionately on vulnerable populations, particularly children, whose developing immune systems make them highly susceptible to the severe and potentially fatal consequences of consuming contaminated water. To mitigate these pressing public health risks and ensure sustainable water security, a multi-tiered intervention strategy is imperative. At the household level, residents must immediately adopt point-of-use water treatment practices such as boiling, chlorination, or solar disinfection prior to any consumption. Concurrently, well owners must implement structural upgrades to their water sources, including the installation of tight-fitting covers, concrete aprons, and proper drainage channels, to effectively block contaminated surface runoff from entering the wells. Beyond individual household actions, systemic regulatory enforcement is crucial. Relevant government and regulatory bodies, specifically the National Agency for Food and Drug Administration and Control (NAFDAC) and the Ministry of Water Resources, must intensify water quality monitoring and strictly enforce the mandated 25-meter separation distance between wells and pit latrines. Finally, to guarantee long-term groundwater protection, comprehensive sanitary surveys should be conducted across the area, coupled with the establishment of trained community water committees tasked with the continuous oversight, education, and maintenance of local water resources.

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