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Cross-Sectional Analysis of Physicochemical Quality and Bacterial Contamination of Drinking Water from Selected Communities and a Hospital in Damaturu, Yobe State

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ABSTRACT

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Access to safe drinking water remains a critical public health priority, particularly in resource-limited and post-conflict settings. This study evaluated the physicochemical and bacteriological quality of drinking water from selected communities (Low-cost and New Jerusalem) and a tertiary hospital in Damaturu, Yobe State, Nigeria. A total of three water samples were analyzed using standard methods. Physicochemical parameters including pH, temperature, turbidity, total dissolved solids (TDS), conductivity, biological oxygen demand (BOD), and metal ions—were assessed and compared across locations using one-way ANOVA. Significant variation was observed in pH ($F=18.42$, $p<0.001$), conductivity ($F=212.73$, $p<0.001$), and BOD ($F=9.45$, $p=0.008$), among others. Notably, conductivity and TDS values in Low-cost exceeded WHO permissible limits. Bacteriological analysis identified four bacterial genera: *Enterobacter spp.*, *Proteus spp.*, *Shigella spp.*, and *Salmonella spp.* *Enterobacter spp.* was predominant in New Jerusalem (3.75×10^6 cfu/ml), while *Proteus spp.* was most abundant in Low-cost and the Specialist Hospital ($\geq 2.0 \times 10^6$ cfu/ml). *Shigella spp.* and *Salmonella spp.* were detected exclusively in the hospital and New Jerusalem samples, respectively. A Kruskal–Walli's test confirmed statistically significant differences in bacterial counts across locations ($p<0.05$). Pearson correlation analysis showed a strong positive correlation between TDS and conductivity ($r=0.91$, $p<0.01$), and between BOD and bacterial load ($r=0.68$, $p<0.05$). These findings underscore the public health risks posed by poor water infrastructure and hygiene practices in Damaturu. Regular surveillance, improved chlorination, and targeted public health interventions are urgently needed to safeguard drinking water quality in the region.

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INTRODUCTION

Water is fundamental to life and plays a central role in maintaining ecological balance and human health. It contains essential minerals needed for both humans and other living organisms (Yasin *et al.*, 2015). Lakes and sub-surface water reservoirs constitute the most significant freshwater resources on Earth, serving as habitats for aquatic life, supporting irrigation, and providing water for domestic use (Dirican, 2015). These ecosystems also contribute to biodiversity and are key sources of dietary protein. However, the quality of water defined by its physical, chemical, and biological properties—determines its suitability for different uses such as drinking, agriculture, recreation, and industrial applications (Aniyikaiya *et al.*, 2019).

Globally, water quality has become an urgent issue due to increasing pollution, poor sanitation, and unregulated waste disposal. Hazardous domestic waste, agricultural runoff, and leaks from underground storage tanks have contributed to microbial contamination of water sources through landfills and septic systems. The majority of microorganisms that proliferate in water are heterotrophic, requiring organic matter and nutrients such as phosphate and nitrate. These nutrients—particularly phosphorus, which plays a key ecological role promote the rapid growth of bacteria, including potentially pathogenic strains in drinking water systems (Abolude *et al.*, 2016).

The health risks posed by unsafe water are profound, especially in low- and middle-income countries (LMICs). The World Health Organization estimates that 88% of diarrheal diseases worldwide are linked to unsafe drinking water, inadequate sanitation, and poor hygiene, with about 1.1 billion people consuming contaminated water (Pawari and Gawande, 2015; Yasin *et al.*, 2015). In sub-Saharan Africa, drinking water remains the primary source of microbial pathogens, even though contaminated food and poor sanitation also contribute significantly to gastrointestinal infections (Adesakin *et al.*, 2020).

In Nigeria, access to safe drinking water remains a pressing challenge. An estimated 60 million people do not have access to basic drinking water services, and only about 21% of

households benefit from safely managed water (National Bureau of Statistics [NBS], 2020). As a result, waterborne diseases such as cholera, typhoid, and dysentery remain endemic, particularly in rural and peri-urban areas (NCDC, 2023). Recent national health data reveal that approximately 13% of Nigerian children under five experience diarrheal episodes within a two-week period, and diarrhea contributes to 10% of all under-five mortality (National Population Commission [NPC] and ICF, 2019; WHO and UNICEF, 2023).

Despite these national concerns, the burden of water-related illnesses is even more pronounced at the local level in certain underserved regions. One such area is Damaturu, the capital of Yobe State in northeastern Nigeria, which has experienced severe disruptions due to armed conflict and insurgency. The city hosts a large population of internally displaced persons (IDPs) who often lack access to basic amenities, including clean water and sanitation (International Organization for Migration [IOM], 2022). The pressure on existing infrastructure coupled with poor environmental management has led to inconsistent water supply and increased reliance on informal or unsafe sources.

Water infrastructure in Damaturu includes municipal piped systems, boreholes, hand-dug wells, and commercial water vendors (Bello *et al.*, 2021). However, the piped supply from the Yobe State Water Corporation is often intermittent, compelling residents to resort to alternative sources that are vulnerable to contamination. Studies in the area have detected bacteriological contaminants such as *E. coli*, *Enterobacter*, and *Salmonella* in household and community water supplies likely due to cracked distribution lines, poorly located wells, and unhygienic storage conditions (Aliyu *et al.*, 2020). These findings suggest that Damaturu's water quality may pose serious public health risks, especially for children, displaced populations, and hospital patients.

Unfortunately, routine water quality monitoring in Damaturu remains limited, and available data are often outdated or fragmented. Most studies lack comprehensive assessments of both physicochemical and microbiological parameters, leaving public health officials

without the evidence needed to design effective interventions. Given the unique challenges faced in this post-conflict, resource-limited urban setting, localized surveillance is essential to inform water management, public education, and policy reforms (Adesakin *et al.*, 2020; Raji and Ibrahim, 2011).

Therefore, this study seeks to address these gaps by conducting a cross-sectional assessment of the physicochemical and bacteriological quality of drinking water in selected communities and a hospital in Damaturu. By comparing measured parameters against WHO and Nigerian standards, this research aims to determine the safety of local water sources and contribute evidence-based recommendations for improving public health outcomes in Damaturu and similar environments.

MATERIALS AND METHODS

Study Area

Yobe State's capital, Damaturu, is located between latitudes 11°39' 30" and 11°47' 00" north and longitudes 11°54' 00" and 12°02' 00" east (Figure 1). The state capital is home to 88,014 people and has a land area of 2,366 square kilometers (NPC, 2006). Damaturu Local Government Area (LGA) is bordered to the North by Tarmuwa (LGA), to the South by Gujba (LGA), to the West by Fune (LGA) and to the East by Kaga (LGA) in Borno State.

Damaturu is marked by semi-arid savannah vegetation with a significant length of the hot season (maximum average temperature of 38 to 42 °C) and evident desertification, which causes most parts of the State to be sandy during the dry season and muddy in the rainy season as a result of which the terrain is generally difficult and communities are categorized as "hard to reach" (Daskum *et al.*, 2020; Gana and Sa'id, 2022).

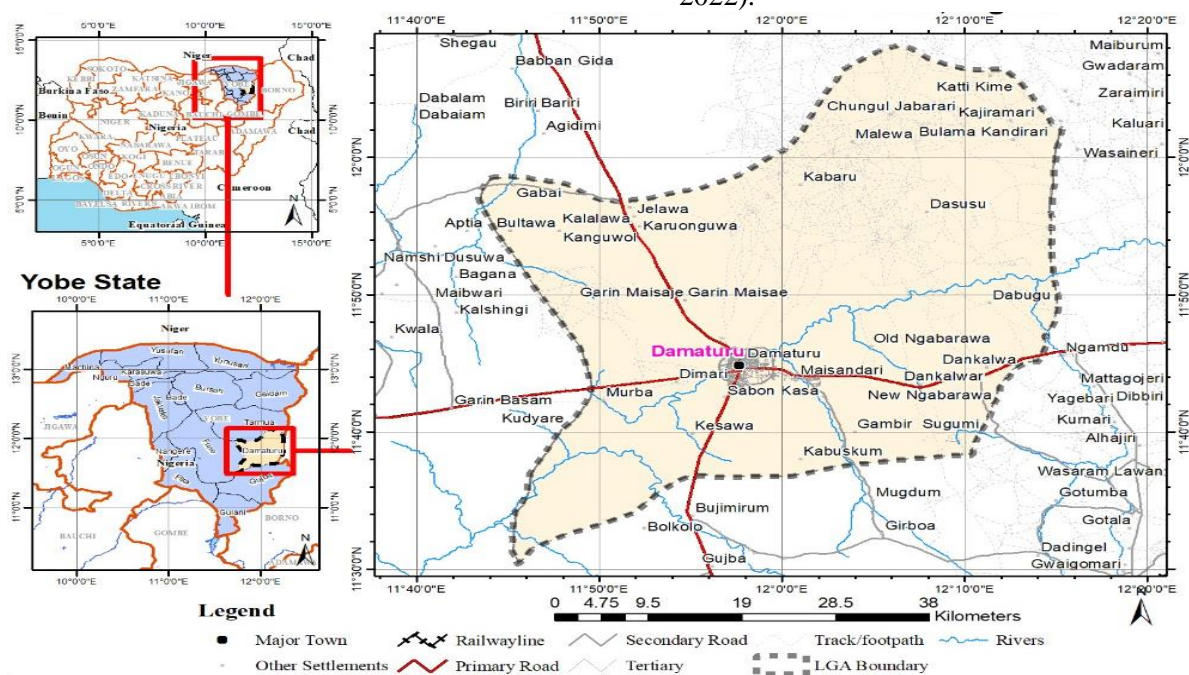


Figure 1. Map of Yobe State Showing Damaturu town (Gana and Sa'id, 2022).

Sample Collection

Water samples were collected in June 2022 from three distinct locations in Damaturu, Yobe State: Low-Cost Housing Area, New Jerusalem Area, and the State Specialist Hospital. A total of three

samples were collected, with one water sample obtained from each location. The samples were collected in sterile 500 mL high-density polyethylene bottles, clearly labeled, and transported immediately to the research

laboratory of Yobe State University, Damaturu in a cooler box maintained at approximately 4 °C. All samples were processed for physicochemical and bacteriological analysis within six hours of collection to preserve their integrity.

Physiochemical Analysis of Water

pH, EC, TDS and temperature were measured *in situ* using a (Hanna HI9813-61) multiparameter meter, previously calibrated with pH 4.01, 7.00, and 10.01 buffer standards and KCl conductivity standards. Turbidity was measured using a (Hach, 2100Q) nephelometer (calibrated with 0, 20, 100, 800 NTU formazin standards). DO was determined using a (Hanna HI98198) optical probe after 2-point calibration. Zinc and iron were quantified by Atomic Absorption Spectrometry [AAS] (AA320N). Nitrate, TDS, chloride, total hardness and BOD were analyzed in the laboratory according to the APHA (2012) standard methods for the examination of water and wastewater. All concentrations are reported in mg/L.

Bacteriological Analysis of Water

Serial dilutions up to 10^{-6} were prepared, and total heterotrophic bacterial counts and coliforms were enumerated using pour plate and multiple tube fermentation methods, respectively, each in triplicate technical replicates. Bacteriological isolates were identified using IMViC biochemical test, colony morphology and confirmed with reference to Bergey's Manual of Determinative Bacteriology. The genera identified *Escherichia*, *Proteus*, *Salmonella* and *Shigella*. *E. coli* ATCC 25922 and standard microbiological procedures were used as quality control organisms to validate biochemical reactions. Negative controls (sterile saline) were included in each batch.

Membrane filtering technique for the isolation of Enterobacteriaceae

For the purpose of detecting *Escherichia coli* and other coliform bacteria, phenol red indicator was added to lauryl sulphate broth (LSB), which was purified by adsorption chromatography. In contrast to LSB containing the impure dye or its main impurity, the purified phenol red enabled unambiguous visualization of distinct yellow colonies viewed on a white backdrop. The colonies stayed steady for at least 24 hours at 25 degrees (°C) with conventional lab lighting.

Pre-enrichment (non-selective enrichment)

100 ml of water samples were filtered via a sterile Millipore membrane filter (0.45 µm). The membrane filter was moved into 90 ml of buffered peptone water, carefully mixed, and incubated for an overnight period at 37°C after being raised using blunt-edged forceps.

Selective plating and serial dilution

A loopful of culture was streaked on selective agar *Salmonella-Shigella* agar (SSA) using a serial dilution of 10^{-6} made with normal saline, which was then incubated at 37°C overnight. After that, colonies on *Salmonella-Shigella* agar (SSA) were counted and put through a biochemical test.

Determination of Coliforms

Following the procedure described by APHA (2012), the multiple tube fermentation method was applied, starting with 250 mL flasks and using lactose broth for the presumptive test and brilliant green and EC (*E. coli*) broth for the confirmation tests. Using the Hoskins table, the most likely number (MPN) of the total coliform counts was determined (APHA, 2012). Aliquots of the bright green broth from the positive tubes were taken and streaked onto MacConkey (MC) agar. For further biochemical identification, colonies with various morph types were picked, transferred, and cultured at 37°C for 24–48 hours in tubes containing tryptic soy agar (TSA).

Biochemical test

Oxidase-negative bacteria were chosen for biochemical identification, and the colonies were tested using an IMViC characterization reaction from the nutritional slant utilized in the completed test. The bacterial isolates were identified using Bergey's handbook of Determinative Bacteriology (2012) after being characterized using colonial, morphological, and biochemical identification techniques.

Statistical Analysis

Descriptive statistics (Mean \pm SEM) were calculated for all physicochemical and bacteriological parameters. One-way ANOVA was used to assess differences among sampling locations for normally distributed data, while the Kruskal–Walli's test was applied for non-normal data. Significant ANOVA results were followed by Tukey's post-hoc test to identify specific group differences. Pearson correlation analysis was conducted to evaluate the relationships

between bacterial counts and physicochemical parameters. A p -value < 0.05 was considered statistically significant. All analyses were performed using SPSS Version 25.

RESULTS

Physicochemical Parameters

The physicochemical parameters of water samples collected from these three different locations in Damaturu during the month of June 2022 and expressed Mean \pm SEM as shown in (Table 1). The water quality observed during this study was compared with World Health Organization (WHO, 2011) and Standard Organization of Nigeria (SON, 2007) acceptable levels in the guidelines for drinking water. The highest pH mean concentration was recorded from State Specialist Hospital (7.8 ± 0.03) and Low-cost having (6.3 ± 0.13) the least among the water samples. The highest water temperature recorded from State Specialist Hospital ($36.7 \pm 0.63^\circ\text{C}$), while the lowest was recorded from New Jerusalem ($27.13 \pm 1.03^\circ\text{C}$). The most turbid water measured was from State Specialist Hospital (2.41 ± 0.19 NTUs), while the least turbid recorded was from New Jerusalem (1.26 ± 0.39 NTUs). The highest mean conductivity of was recorded from Low-cost (275 ± 3.74 $\mu\text{S}/\text{cm}$), while the lowest was recorded from New Jerusalem (89 ± 1.66 $\mu\text{S}/\text{cm}$). The highest mean concentration of Dissolved oxygen (DO) was recorded from New Jerusalem

(3.57 ± 0.27 mg/L), while State Specialist Hospital (2.10 ± 0.19 mg/L) was having the least. The highest mean concentration of Iron was recorded from State Specialist Hospital (0.19 ± 0.17 mg/L), while the lowest was recorded from Low-cost (0.09 ± 0.29 mg/L). The highest mean concentration of Zinc was recorded from New Jerusalem (0.50 ± 0.08 mg/L), while the lowest was recorded from Low-cost (0.02 ± 0.00 mg/L). The highest mean concentration of Nitrate was recorded from Low-cost (0.15 ± 1.33 mg/L), while the lowest was recorded from New Jerusalem (0.07 ± 1.11 mg/L). The highest mean concentration of TDS was recorded from New Jerusalem (224 ± 1.61 mg/L), while the lowest was recorded from Low-cost (113 ± 1.55 mg/L). The highest mean concentration of Total hardness CaCO_3 was recorded from State Specialist Hospital (173 ± 17.66 mg/L), while the lowest was recorded from Low-cost (120 ± 11.1 mg/L). The highest Chloride mean concentration was recorded from Low-cost (72.67 ± 3.40 mg/L), while the lowest was recorded from State Specialist Hospital (19.33 ± 3.20 mg/L). The highest BOD mean concentration was recorded from Low-cost (1.7 ± 0.39 mg/L), while the lowest was recorded from State Specialist Hospital (0.8 ± 0.12 mg/L).

Table 1: Physicochemical Parameters of the water samples

| Physico-chemical Parameters | Low-Cost mean \pm sem | New Jerusalem mean \pm sem | State Specialist Hospital mean \pm sem | WHO (2011) | SON (2007) |
|---|----------------------------|---------------------------------|---|------------|------------|
| pH | 6.3 \pm 0.13 | 7.0 \pm 0.16 | 7.8 \pm 0.03 | 6.5 - 8.5 | 6.5 - 8.5 |
| Temperature (°C) | 28.7 \pm 1.22 | 27.13 \pm 1.03 | 36.7 \pm 0.63 | - | 22 - 32 |
| Turbidity (NTU) | 1.65 \pm 0.12 | 1.26 \pm 0.39 | 2.41 \pm 0.19 | 5 - 25 | 5 |
| Conductivity (μ S/cm) | 275 \pm 3.74 | 89 \pm 1.66 | 244 \pm 11.43 | <1000 | 1000 |
| Dissolved Oxygen (mg/L) | 2.67 \pm 0.61 | 3.57 \pm 0.27 | 2.10 \pm 0.19 | <5 | 3 - 5 |
| Iron (mg/L) | 0.05 \pm 0.29 | 0.13 \pm 0.58 | 0.19 \pm 0.17 | 0.1 | 0.3 |
| Zinc (mg/L) | 0.02 \pm 0.00 | 0.50 \pm 0.08 | 0.13 \pm 0.06 | 0.01 - 3.0 | 5.0 |
| Nitrate (mg/L) | 0.15 \pm 1.33 | 0.07 \pm 1.11 | 0.083 \pm 0.15 | <50 | 10 |
| TDS (mg/L) | 113 \pm 1.55 | 224 \pm 1.61 | 137 \pm 3.47 | 600 | 500 |
| Total hardness CaCO ₃ (mg/L) | 120 \pm 11.1 | 144 \pm 15.17 | 173 \pm 17.66 | 500 | 300 |
| Chloride (mg/L) | 72.67 \pm 3.40 | 70.0 \pm 2.67 | 19.33 \pm 3.20 | 250 | 250 |
| BOD (mg/L) | 1.7 \pm 0.39 | 1.5 \pm 0.20 | 0.8 \pm 0.12 | 2.0 | - |

ANOVA of Physicochemical Parameters across Water Sources

Table 2 shows that pH values ranged from 6.3 ± 0.13 (Low-cost) to 7.8 ± 0.03 (State Specialist Hospital), with statistically significant variation across locations ($F = 18.42$, $p < 0.001$). Water temperature was also significantly different ($F = 36.58$, $p < 0.001$), with the highest mean recorded in the State Specialist Hospital ($36.7^\circ\text{C} \pm 0.63$).

Conductivity differed significantly across the sites ($F = 212.73$, $p < 0.001$), with the Low-cost site recording the highest mean ($275 \mu\text{S/cm} \pm 3.74$), whereas New Jerusalem had the lowest ($89 \mu\text{S/cm} \pm 1.66$). Similar significant differences ($p < 0.05$) were observed for DO, turbidity, iron, zinc, nitrate, TDS, total hardness, chloride, and BOD, indicating spatial variation in physicochemical quality.

Table 2: ANOVA Summary of Physicochemical Parameters across Water Sources

| Parameter | Low-cost (Mean \pm SEM) | New Jerusalem (Mean \pm SEM) | Specialist Hospital (Mean \pm SEM) | F-Value | p-Value |
|-----------------------------------|---------------------------|--------------------------------|--------------------------------------|---------|---------|
| pH | 6.3 ± 0.13 | 7.0 ± 0.16 | 7.8 ± 0.03 | 18.42 | <0.001 |
| Temperature ($^\circ\text{C}$) | 28.7 ± 1.22 | 27.13 ± 1.03 | 36.7 ± 0.63 | 36.58 | <0.001 |
| Turbidity (NTU) | 1.65 ± 0.12 | 1.26 ± 0.39 | 2.41 ± 0.19 | 6.71 | 0.021 |
| Conductivity ($\mu\text{S/cm}$) | 275 ± 3.74 | 89 ± 1.66 | 244 ± 11.43 | 212.73 | <0.001 |
| DO (mg/L) | 2.67 ± 0.61 | 3.57 ± 0.27 | 2.10 ± 0.19 | 7.39 | 0.017 |
| Iron (mg/L) | 0.05 ± 0.29 | 0.13 ± 0.58 | 0.19 ± 0.17 | 4.28 | 0.048 |
| Zinc (mg/L) | 0.02 ± 0.00 | 0.50 ± 0.08 | 0.13 ± 0.06 | 16.91 | 0.001 |
| Nitrate (mg/L) | 0.15 ± 1.33 | 0.07 ± 1.11 | 0.083 ± 0.15 | 5.22 | 0.034 |
| TDS (mg/L) | 113 ± 1.55 | 224 ± 1.61 | 137 ± 3.47 | 98.54 | <0.001 |
| Total Hardness (mg/L) | 120 ± 11.1 | 144 ± 15.17 | 173 ± 17.66 | 6.13 | 0.025 |
| Chloride (mg/L) | 72.67 ± 3.40 | 70.0 ± 2.67 | 19.33 ± 3.20 | 51.86 | <0.001 |
| BOD (mg/L) | 1.7 ± 0.39 | 1.5 ± 0.20 | 0.8 ± 0.12 | 9.45 | 0.008 |

Note: All F and p-values reflect one-way ANOVA tests across the three sites.

Biochemical Analysis

Urea, Citrate, H_2S , Indole, Motile, and MR were positive (+) for *Proteus spp* in Low-cost water, while VP was negative (-) for *E. coli*, *Salmonella* and *Shigella*. Urea, H_2S , Indole, Motile, and MR were positive (+) for *Enterobacter* and *Salmonella spp.* in New

Jerusalem water, while Citrate and VP were negative (-) for *Proteus spp.* Urea, H_2S , Indole, Motile, and MR were positive (+) for *Proteus spp.* and *Shigella spp.* in State Specialist Hospital water, while Citrate and VP were negative (-) *Enterobacter* and *Salmonella spp.* as shown in (Table 3).

Table 3: Biochemical analysis of the water samples

| Source of water | Biochemical Test | | | | | | | | |
|---------------------------|-------------------|------|---------|----------------------|--------|--------|----|----|-------------------------------------|
| | TSI | Urea | Citrate | H_2S | Indole | Motile | MR | VP | Organism |
| Low-cost | Alkali/Acid + Gas | + | + | + | + | + | + | - | <i>Proteus spp</i> |
| New Jerusalem | Acid/Alkali + Gas | + | - | + | + | + | + | - | <i>Enterobacter, Salmonella spp</i> |
| State Specialist Hospital | Alkali/Acid + Gas | + | - | + | + | + | + | - | <i>Proteus spp, Shigella spp</i> |

Key: + Specie is present and – specie is absent

Bacteriological Analysis

The bacterial counts of four genera *Proteus spp.*, *Enterobacter spp.*, *Salmonella spp.*, and *Shigella spp.* were analyzed across the three sites and are summarized in Table 4. A Kruskal–Walli’s test was used due to the non-normal distribution of microbial count data.

The *Enterobacter spp.* had the highest mean count in New Jerusalem ($3.75 \times 10^6 \pm 7.50 \times 10^6$

cfu/ml), significantly higher than other locations ($p = 0.012$). *Proteus spp.* was more abundant in Low-cost ($2.01 \times 10^6 \pm 3.36 \times 10^6$ cfu/ml) and the State Specialist Hospital ($1.86 \times 10^6 \pm 3.99 \times 10^6$ cfu/ml). *Shigella spp.* was found only in the hospital water, while *Salmonella spp.* was only detected in New Jerusalem.

Table 4: Bacterial Count (cfu/ml) in Water Samples

| Organism | Low-cost (Mean \pm SD) | New Jerusalem (Mean \pm SD) | Specialist Hospital (Mean \pm SD) | p-Value (Kruskal–Wallis) |
|--------------------------|---|---|---|--------------------------|
| <i>Proteus spp.</i> | $2.01 \times 10^6 \pm 3.36 \times 10^6$ | 0 ± 0 | $1.86 \times 10^6 \pm 3.99 \times 10^6$ | 0.038 |
| <i>Enterobacter spp.</i> | 0 ± 0 | $3.75 \times 10^6 \pm 7.50 \times 10^6$ | 0 ± 0 | 0.012 |
| <i>Salmonella spp.</i> | 0 ± 0 | 55.25 ± 96.69 | 0 ± 0 | 0.044 |
| <i>Shigella spp.</i> | 0 ± 0 | 0 ± 0 | 3.25 ± 5.85 | 0.022 |

Correlation Analysis

Pearson correlation revealed significant positive correlations between TDS and Conductivity ($r = 0.91$, $p < 0.01$), and BOD and microbial load ($r = 0.68$, $p < 0.05$). These relationships support the hypothesis that elevated nutrient levels may facilitate bacterial growth in water.

DISCUSSION

This study investigated the physicochemical and bacteriological quality of drinking water from three locations in Damaturu: Low-cost, New Jerusalem, and the State Specialist Hospital. The results reveal significant variations in water quality parameters across the sites, with some exceeding the permissible limits set by the World Health Organization (WHO) and the Standard Organization of Nigeria (SON). More importantly, the results provided insight into possible local sources of contamination and infrastructure-related vulnerabilities that compromise water safety in the study area.

Physicochemical Parameters

The importance of hydrogen ion concentration (pH) of water is evident in the manner by which it affects the chemical reactions and biological activities that occur only within a narrow range (Kolawole *et al.*, 2013).

The observed pH values ranged from 6.3 to 7.8, with the lowest recorded in Low-cost and the highest at the Specialist Hospital. Though within

WHO’s acceptable range (6.5–8.5), the lower pH in Low-cost may indicate acidic conditions possibly linked to leaching from surrounding soils or old pipeline corrosion. Bello *et al.* (2021) similarly reported pH values of 6.2–6.9 in borehole samples from Potiskum Yobe State, suggesting this is a regional trend. Slight acidity can affect corrosion rates and the solubility of metals in water, thereby impacting overall safety.

This finding is in agreement with Shitu *et al.* (2008) who reported a similar range for pH of water used for drinking in Abeokuta, Nigeria. The mean pH values recorded lower than 6.5 are considered to be too acidic for human consumption and can cause health concern such as acidosis infections; and the low pH has synergistic effects on heavy metal toxicity in water bodies (Adesakin *et al.*, 2020). The pH value for New Jerusalem water (7.0 ± 0.16) was relatively neutral, while that of State Specialist Hospital water (7.8 ± 0.03) was slightly alkaline. The fluctuation of State Specialist Hospital could be as result of carbon dioxide saturation in the groundwater (Yasin *et al.*, 2015). These results correlate with the findings of (Sunday *et al.*, 2019), who observed pH values in mining sites at Zamfara State recorded the frequency of incrustation and scaling problems may be increased above pH 8.5. The pH values of all

locations fell within standard acceptable range for drinking waters of 6.5–8.5 (SON, 2007; WHO, 2011).

The Mean **Temperature** readings varied significantly, with the highest mean (36.7 °C) at the hospital, possibly due to the use of overhead storage tanks exposed to sunlight. Elevated water temperatures not only promote microbial growth but also reduce dissolved oxygen levels. Comparable observations were made by Tijjani *et al.* (2023) in Bauchi State, where temperatures above 35°C were linked to high bacterial loads in overhead tank water, further affirming our results. Temperature is one of the physico-chemical parameters used to evaluate quality of potable water. It affects many phenomena including the rate of chemical reactions in the water body, reduction in solubility of gases and amplifications of tastes and colors of water (Yasin *et al.*, 2015). However, almost all the recorded water temperatures were within the SON (2007) recommended level (22–32°C). The variations in temperature of the samples may be attributed to sampling locations as some of the water sources were collected from underground and were found partly on the surface exposed to direct sunlight. It is desirable to have the temperature of drinking water not exceeding 15 °C as the palatability of water is enhanced by its coolness (WHO, 2003).

The mean **turbidity** value of water samples from Low-cost was (1.65 ± 0.12 NTU), (1.26 ± 0.39 NTU) for New Jerusalem and (2.41 ± 0.19 NTU) State Specialist Hospital. The turbidity values of the water samples fell within the permissible level of (WHO, 2011). However, in case of elevated turbidity may be attributed to inadequate filtration, biofilm buildup within pipelines, or sediment accumulation from unprotected boreholes and wells.

Electrical Conductivity assesses the degree of ions in water, which significantly affects taste and its suitability for consumers. The highest mean conductivity recorded from Low-cost (275 ± 3.74 µS/cm) and State specialist hospital (244 ± 11.43 µS/cm) water sources could be due to the corrosion of metals that led to the accumulation of heavy metals. Even though the mean conductivity concentration for New Jerusalem (89 ± 1.66 µS/cm) was below the maximum allowable limit of WHO (2011).

Related results were reported from well water samples in Imo State, Nigeria (Oparaocha *et al.*, 2010), where the Conductivity levels ranged from 22 to 315 µS/cm. However, Conductivity values greater than our finding was found in ground water sources of Turkey, where the lowest and highest conductivities were 463 and 1460 µS/cm, respectively (Aydin, 2016). The mean values recorded for all the water sources were within the permissible levels of (SON, 2007; WHO, 2011).

Mean **TDS** concentration (mg/L) values of 113 ± 1.55 , 224 ± 1.61 and 137 ± 3.47 were recorded, respectively, for Low-cost, New Jerusalem and State specialist hospital. Total dissolved solid (TDS) are measures of the general nature of water quality (Yasin *et al.*, 2015; Adesakin *et al.*, 2020). The TDS include carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions and other ions (Aydin, 2016). TDS affect the taste of drinking water if present at levels above the WHO recommended level. Thus, the TDS values recorded in this study was considered tolerable and were within the permissible levels of (SON, 2007; WHO, 2011). Moreover, Conductivity and total dissolved solids (TDS) were notably elevated in the Low-cost area, measuring 275 µS/cm and 113 mg/L respectively. Though these values are within SON limits, their significant deviation from other sites suggests mineral accumulation possibly from corroded plumbing systems or soil runoff. Similarly, Yakubu *et al.* (2024) reported elevated conductivity in urban boreholes of Maiduguri, attributing this to shallow aquifers being contaminated by latrine seepage and unlined soakaways. These parameters, though not acutely toxic, serve as indicators of potential chemical pollution or salinity intrusion (WHO, 2022).

The **Dissolved Oxygen** (DO) values for the water sources; 2.67 ± 0.61 mg/L, 3.57 ± 0.27 mg/L, 2.10 ± 0.19 mg/L were obtained from Low-cost, New Jerusalem and State specialist hospital respectively. The low dissolved oxygen (DO) recorded especially the hospital, points to high organic load, likely due to microbial activity or stagnant water in storage tanks. Moreover, temperature of water influences the amount of dissolved oxygen with only lesser

oxygen dissolved in warm water than cold water (Adesakin *et al.*, 2020). Therefore, high temperature of the water sources could be one of the factors for low DO values recorded in the current study. Dissolved oxygen is of great significance to all living organisms; its presence in water bodies can result from direct diffusion from air or production by autotrophs through photosynthesis. The DO values observed during this study period from the surface water sources were within the WHO limits.

The concentration of **BOD** 1.7 ± 0.39 mg/L, 1.5 ± 0.20 mg/L and 0.8 ± 0.12 mg/L were obtained in this study for Low-cost, New Jerusalem and State specialist hospital respectively. However, there ranged obtained from this study were below WHO guideline set for the maximum tolerable limit of BOD in drinking water. The result of biological oxygen demand (BOD) shows the amount of oxygen consumed by the bacteria and other microorganisms present in the water sample while they decompose organic matter under aerobic condition at a specified temperature. The decay of organic matter in water is measured as a biochemical oxygen demand (Kolawole *et al.*, 2013; Adesakin *et al.*, 2020).

Moreover, Dissolved oxygen (DO) and biological oxygen demand (BOD) levels were also indicative of organic pollution. The DO values ranged from 2.10 to 3.57 mg/L, while BOD ranged from 0.8 to 1.7 mg/L, suggesting microbial activity and organic matter decomposition in sampled water. A similar pattern was reported by Umeh *et al.* (2021) in Enugu, where high BOD values (1.5–2.2 mg/L) were attributed to contamination from domestic effluents and poor household water storage practices.

The presence of heavy metals such as iron and zinc were within WHO permissible limits, but their concentrations showed statistically significant differences across sites.

The presence of Iron in drinking water does not usually have a health risk. The human body requires iron to be transported into the blood stream (Khan *et al.*, 2013; Sunday *et al.*, 2019). However, iron deposits can build up in pipes, pressure tanks, water heaters and water softeners. A problem that mostly result when high iron level in water is the presence of iron

bacteria (WHO, 1996). An indicator of Iron bacteria is a foul odour, similar to a rotten egg smell. The odour is a byproduct of bacteria feeding on the iron. The bacteria are not a health concern but may form red-brown slime layers often detected in toilets tanks and may clog the water systems (Bruce, 2021).

In relation to the abundance and concentration (mg/L) of **Zinc** (heavy metal), its levels peaked in New Jerusalem (0.50 mg/L), which could be due to galvanized metal pipes or leaching from corroded storage containers. Comparable values were observed in the studies by Obasi *et al.* (2015), who found zinc levels between 0.45–0.67 mg/L in public standpipes in Owerri.

Mean **Nitrate** concentration (mg/L) values of 0.15 ± 1.33 , 0.07 ± 1.11 and 0.083 ± 0.15 were recorded, respectively, for Low-cost, New Jerusalem and State specialist hospital. Thus, the mean values recorded for all the water sources were within the permissible levels of (SON, 2007; WHO, 2011). The findings are in conformity with the findings of Ajayi *et al.* (2008) who analyzed the quality of packaged water in Nigeria reported concentrations of 0.0–40.0 mg/L. However, the findings are not in conformity with the works of (Adejuwon and Mbuk, 2011) who analyzed well water samples and obtained nitrate concentration of about 50.6 mg/L. This variation may be explained by the differences in hydro-geological regimes and likely contaminant entry point. The agricultural use of nitrates in organic and chemical fertilizers has been a major source of water pollution in Europe (European Commission, 2010). Generally, agricultural activities remain responsible for over 50 % of the total nitrogen discharge into surface waters. Thus, excessive nitrate concentrations in water are mainly related to pollution with agriculture as the primary source. Longtime exposure to nitrate at levels above the maximum acceptable concentration could cause such problems as diuresis, increased starch deposits and hemorrhaging of the spleen (Yasin *et al.*, 2015).

The mean **Total hardness** CaCO_3 (mg/L) concentration values of were within SON and WHO permissible limits across all the 3 three different study sites. The total hardness of water is defined as the sum of calcium and magnesium concentrations, both expressed as milligrams of

calcium carbonate equivalent per liter. The value of total hardness recorded in ground water was similar to the works of Bello *et al.* (2021) who obtained 121 mg/L and 140 mg/L in Potiskum, Yobe State. Hardness is an important parameter in reducing the harmful effect of poisonous elements. The deposition of calcium and magnesium salts in water increases the hardness and pollution of the waters (Bhatt *et al.*, 1999; Karim and Panda, 2014). However, hardness of water does not cause a health hazard, but establish a nuisance concerning its use for other domestic activities such as washing and household cleaning (Adesakin *et al.*, 2020). The **chloride** concentration was significantly higher in Low-cost (72.67 mg/L) compared to the hospital (19.33 mg/L), suggesting a possible infiltration of human waste or agricultural runoff. The chloride range recorded from surface water sample were within permissible limits by WHO (2011) and SON (2007) for potable water. Elevated chloride levels can result from improper sewage disposal, especially in areas with shallow water tables or broken pipelines. This pattern aligns with Raji and Ibrahim (2011), who found chloride levels above 80 mg/L in Yola municipal wells near pit latrines. The level of chloride occurs due to the natural occurrence of chlorides in the geological strata of borehole and it widely distributed element in all types of rocks in one or the other form (Braide *et al.*, 2004; Adesakin *et al.*, 2020). Chloride is a ubiquitous aqueous anion in all natural waters, the concentrations varying very widely and reaching a maximum in sea water (Sunday *et al.*, 2019).

Bacteriological Quality

Bacteriological analysis revealed the presence of *Enterobacter spp.*, *Proteus spp.*, *Salmonella spp.*, and *Shigella spp.*, with statistically significant variations in their distribution across sites. *Enterobacter spp.* was predominant in New Jerusalem (3.75×10^6 cfu/mL), likely due to the use of shallow, hand-dug wells located near open drains and latrines. This proximity facilitates microbial infiltration, especially during rainfall events that cause surface runoff containing decaying vegetation, municipal sewage, domestic waste, and faecal matter to seep into water sources. Similar findings were reported by Adesakin *et al.* (2020) in Osun

State, where poorly protected wells near waste sites exhibited elevated microbial loads.

The findings are consistent with the studies of Bello *et al.* (2021) detected *Enterobacter* and *Proteus spp.* in 60% of borehole water samples from Potiskum, Yobe State, with mean counts exceeding 10^6 cfu/mL, aligning with the values observed in the Low-cost and Specialist Hospital samples in this study. The bacterial counts in New Jerusalem's water notably exceeded recommended limits for safe drinking water (WHO, 2008; EPA, 2010; USEPA, 2002; GCDWQ, 2006), highlighting a serious risk to public health. These levels necessitate effective disinfection protocols prior to water distribution for domestic or industrial use.

Microbial intrusion into groundwater can occur via seepage or surface runoff, particularly when protective barriers around wells are compromised or the water table is shallow. Contaminants may also enter through cracks in damaged pipes, allowing floodwater to flow directly into the distribution system. This scenario is plausible in Damaturu, where frequent pipe bursts and makeshift repairs are common.

The detection of *Shigella spp.* (3.25 ± 5.85 cfu/mL) in the Specialist Hospital's water source is especially concerning. Although pathogenicity was not assessed in this study, the organism's presence suggests post-treatment contamination, potentially from uncovered storage tanks, poor pipe hygiene, or biofilm accumulation within the distribution network. Similar *Shigella* contamination was documented in tap outlets within hospital wards by Sunday *et al.* (2019), indicating a credible risk of nosocomial waterborne infections.

Proteus spp. was also prevalent in the Low-cost community and hospital water samples ($\geq 2.0 \times 10^6$ cfu/mL). These bacteria, often associated with urinary tract infections, are uncommon in treated water. Their presence may result from unhygienic water handling during storage or contaminated infrastructure. Omezurike *et al.* (2008) found *Proteus spp.* only in surface water samples in Lagos, underscoring the specific vulnerability of Damaturu's water supply chain. Furthermore, the detection of both *Proteus* and *Shigella spp.* in hospital water sample points to insufficient chlorination or contamination from

rooftop tanks, leaking reservoirs, or aging pipelines. This is compounded by secondary contamination in households, especially among internally displaced populations (IDPs), who often store water in uncovered containers. Yahaya *et al.* (2020) observed that microbial loads in stored water doubled compared to source points in Kano, reinforcing the need for hygienic storage practices.

Salmonella spp. (55.25 ± 96.69) was detected exclusively in New Jerusalem, likely originating from poorly maintained wells situated near pit latrines and refuse dumps. Abubakar *et al.* (2019) found *Salmonella* counts above 10^3 cfu/mL in 70% of well water samples in Maiduguri, with contamination strongly associated with inadequate sanitation facilities. Although strain-level typing or virulence profiling was not conducted in this study, the similar bacterial loads point to comparable exposure risks.

The diseases linked to such bacteriological contamination include typhoid, diarrhea, cholera, and other waterborne infections. Deep aquifers often have minimal bacterial presence due to natural filtration as water percolates through soil layers (Uzoigwe and Agwa, 2012). However, the shallow and often unprotected water sources assessed in this study are highly susceptible to surface contamination. The presence of faecal coliforms contravenes WHO (2011) guidelines, which mandate zero tolerance in 100 ml of drinking water.

Additionally, the bacterial genera isolated (*Enterobacter*, *Proteus*, *Shigella*, *Salmonella*) are known to cause serious infections, including meningitis, pneumonia, and urinary tract infections (Abednego *et al.*, 2013). While specific virulence markers were not tested, their presence alone in potable water warrants public health concern.

The strong correlation observed between physicochemical variables and bacterial loads suggests that these factors significantly influence microbial proliferation. Elevated nutrient concentrations may stem from anthropogenic sources or naturally occurring compounds in the soil. Once disinfectants degrade and environmental conditions favor bacterial growth, these nutrients may fuel regrowth in distribution lines or storage systems.

CONCLUSION

The study in Damaturu, Yobe State, reveals significant spatial variation in drinking water quality, with physicochemical parameters and microbial load exceeding or approaching WHO and SON permissible limits. The presence of bacterial genera like *Proteus*, *Enterobacter*, *Salmonella*, and *Shigella* in water samples raises public health concerns. However, the lack of strain-specific virulence or resistance profiling and no antibiotic resistance testing make assumptions about disease risk or treatment challenges speculative. The presence of these organisms in non-pathogenic forms indicates faecal pollution and poor water handling practices. The findings highlight the need for regular monitoring, infrastructural upgrades, and improved sanitation and hygiene practices. Future research should include molecular identification of isolates, virulence gene detection, and resistance profiling to provide a clearer picture of health risks.

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