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# SEASONAL VARIATION IN PHYSICOCHEMICAL PARAMETERS OF WELL WATERS IN MAKURDI METROPOLIS OF BENUE STATE, NIGERIA: IMPACT ON WATER QUALITY AND HUMAN HEALTH

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## ABSTRACT

Access to safe drinking water remains a critical public health challenge in rapidly urbanising cities of sub-Saharan Africa, where reliance on unprotected groundwater sources is widespread. This study evaluated the seasonal portability and human health implications of well water in Makurdi metropolis, Benue State, Nigeria, using integrated physicochemical and bacteriological indicators. Water samples were collected in triplicate from sixteen open wells distributed across the four cardinal zones of the city during both wet and dry seasons. Samples were analysed for turbidity, pH, electrical conductivity, and other physicochemical parameters following standard APHA protocols, with results benchmarked against the WHO and Nigerian Standard for Drinking Water Quality guidelines. Findings revealed that while most physicochemical parameters fell within permissible limits, several samples exceeded safety thresholds seasonally. Wet-season turbidity exceeded the 5 NTU limit at Northbank (3.25–6.23 NTU), Wadata, and Otukpo Road (4.63–6.75 NTU), indicating elevated suspended solids and a potential risk of microbial contamination. Electrical conductivity deviated from the recommended 0.5–1.5 µS/cm at the North bank during the dry season (1.97–2.11 µS/cm) and at Otukpo Road in the wet season (0.13–0.47 µS/cm), suggesting ionic imbalance and possible contamination from anthropogenic activities. Statistical analysis showed that seasonal variation significantly influenced most physicochemical properties ($p < 0.05$), except for pH and EC, underscoring the vulnerability of shallow wells to rainfall-driven runoff and dilution. The observed seasonal exceedances imply increased exposure risks to waterborne pathogens and gelogenic contaminants for communities dependent on these wells. The study concludes that Makurdi's open wells exhibit marked seasonal instability in water quality, necessitating targeted groundwater protection strategies, regular monitoring, and public health interventions to mitigate health risks and ensure sustainable access to potable water.

**Keywords:** Groundwater quality; Seasonal variation; Physicochemical parameters; Turbidity; Electrical conductivity; Open wells; Drinking water safety; Public health

## 1.0 INTRODUCTION

Safe and clean water is a fundamental human right, vital for maintaining health and preventing waterborne diseases. (WHO, 2017). In many developing countries, including Nigeria, well water is a major source of drinking water for millions, especially in rural areas (Nwankwoala, 2011). However, the quality of well water can be compromised by seasonal variations in physicochemical parameters, with significant implications for human health (Singh *et al*., 2013). Makurdi, the capital city of Benue State in Nigeria, is experiencing rapid population growth and urbanisation, which is increasing pressure on water resources (Audu *et al*., 2018). The city's geology, characterised by shallow aquifers and fractured rock formations, makes it vulnerable

Water pollution (Offodile, 2002). Previous studies have reported varying levels of physicochemical parameters in well waters in Makurdi. However, there is limited research on the seasonal variation of these parameters and their impact on water quality and human health (Ezeh *et al*., 2015).This study aims to investigate seasonal variations in the physicochemical parameters of well water in Makurdi and assess their impact on water quality and human health. The study will provide valuable insights into groundwater quality dynamics in the study area and inform policy decisions to ensure access to safe, clean water for the population.

## 2.0 MATERIALS AND METHODS

### 2.1 The Study Area

Makurdi, the study area, is situated at Long. 8 ° 10' N and 8 ° 45' N; and Lat. 7 ° 11' E and 7 ° 45' E in the Southern Guinea Savanna of Nigeria. The town is drained by the River Benue, which bisects it into two

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parts – the North and South banks. Other minor rivers that drain the town and, in turn, empty into the River Benue include Rivers Idye, Genabe, Unudu, Kpege, and Kereke. These rivers are highly seasonal, drying up in the dry season, with some stagnant pools in their channels. Due to the general low relief of Makurdi town, large portions of the area are waterlogged and flooded during heavy rainstorms. Two major climate seasons are recognised: the dry season, which runs from November to March, and the wet season, which runs from April to October, with a short break in mid-August. The average annual precipitation exceeds 220mm and is a major source of groundwater replenishment. Temperature ranges between 21.3 °C and 32.8 °C (Attah *et al.,* 2020). A map of Makurdi is presented in Figure 1.

**2.2 Study Design and Sample Collection**

Sixteen (16) open wells were randomly sampled in the study area based on availability and accessibility. Locations and areas of open well water sampled within Makurdi metropolis are given in Table 1. Water samples were collected from 16 open wells across four (4) cardinal locations, with four (4) sampling points per location. The four cardinal locations and their codes were: North bank (NB), Wadata (WD), Gboko road (GB), and Otukpo road (OT). From each sampling point, water samples were collected in the wet season (October 2024) and dry season (January 2025). The two seasons were coded as "R" for wet season and "D" for dry season. The four sampling points per location were coded as R1-R4 in the wet season or D1-D4 in the dry season.

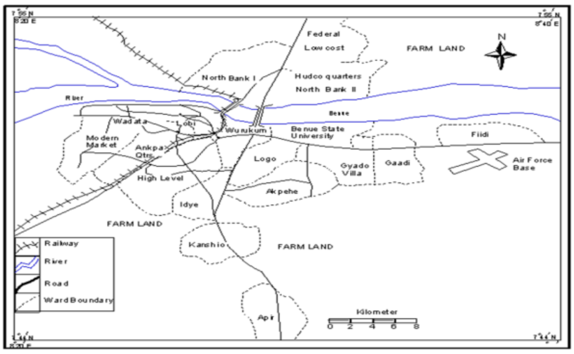


**Figure 1: Map of Makurdi Local Government Area (Attah *et al.,* 2020).**

**Table 1: Locations of Well Water Samples**

| Sample code | Area | Location |
|---|---|---|
| NB1 | Ishwa | North bank |
| NB2 | Northbank market | North bank |
| NB3 | SRS area | North bank |
| NB5 | Lafia junction | North bank |
| WD1 | New garage | Wadata |
| WD2 | New garage | Wadata |
| WD3 | Market area | Wadata |
| WD4 | Mosque area | Wadata |
| GB1 | Apehe | Gboko road |
| GB2 | Apehe | Gboko road |
| GB3 | Back of Epidemiology | Gboko road |
| GB4 | Opp NAF base | Gboko road |
| OT1 | Tse Chivir Welfare | Otukpo road |
| OT2 | Tse Chivir Welfare | Otukpo road |
| OT3 | Opp GTB | Otukpo road |
| OT4 | Yakyo | Otukpo road |

**2.3 Physico-chemical Assessment of Water Samples**

**2.3.1 Determination of pH**

Palintest pH methods use standard pH indicators in tablet form. Different indicators are used to cover different ranges. Each tablet contains the precise amount of indicator needed for the test. All Palintest pH tablets contain a dechlorinating agent, allowing the test to be carried out in water containing chlorine or other disinfectant residuals. This was carried out by filling a test tube with the sample to the 10 ml mark, adding one pH indicator tablet, crushing and mixing to dissolve, then selecting the appropriate Phot number on the Photometer and taking a reading.

**2.3.2 Determination of Temperature**

The surface water temperature was measured in situ using a portable digital thermometer (HANNA Model). The thermometer was lowered into the water sample collected at the designated sites, and the measured temperature was recorded. The mean values of three of these readings were calculated and recorded (Akaahan *et al.,* 2016).

**2.3.3 Determination of Colour**

The colour of the water was determined photoelectrically using the Palintest Photometer. The sample was filtered to remove suspended solids before analysis to determine the 'true colour' due to dissolved matter. The colour of water was expressed using the platinum/cobalt colour scale (Pt/Co scale). Each unit was equivalent to the colour produced by 1 mg/l platinum in the form of chloroplatinic acid in the presence of 2 mg/l cobaltous chloride hexahydrate. These units are identical to 'Hazen' units, which have traditionally been used to express results from visual estimation of water colour (Asen *et al.,* 2019).

**2.3.4 Determination of Turbidity**

The turbidity of the water was determined photoelectrically using the Palintest Photometer. In many samples, both colour and turbidity were present. To separate the effects of turbidity and colour, the sample was compared with a filtered portion of the same water. The Palintest method has been calibrated against the widely recognised formazin turbidity solutions. Turbidity is expressed in terms of Formazin Turbidity Units (FTU). These units are broadly equivalent to Jackson Turbidity Units (JTU) and Nephelometric Turbidity Units (NTU) (Asen *et al.,* 2019).

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### 2.3.5 Determination of Conductivity and Total Dissolved Solids (TDS)

The conductivity was determined using a Palintest conductivity meter. The meter was placed in the bottled water, and the conductivity reading was taken. To obtain the value for total dissolved solids, the mode was pressed again, and that gave the value of TDS (Asen *et al.,* 2019).

### 2.3.6 Determination of Hardness

The Palintest Hardicol test is based on a unique colourimetric method. The reagents are provided in tablet form, and the test is performed by simply adding the appropriate tablets to a water sample. Under the controlled conditions of the test, calcium and magnesium ions react with Hardicol indicator to produce a purple colouration. The intensity of the colour is proportional to the water's total hardness and is measured with a Palintest Photometer. The Total Hardness result was reported in mg/L CaCO3 (Asen *et al.,* 2019).

### 2.3.7 Determination of Nitrate

The Nitratest Tube was filled with the sample to the 20 ml mark, then one level spoonful of Nitratest Powder and one Nitratest tablet were added. Without crushing the tablet, replace the screw cap, shake the tube well for 1 minute, allow it to stand for about 1 minute, then gently invert 3 or 4 times to aid flocculation, and allow it to stand for 2 minutes or longer to ensure complete settlement. This was followed by removing screw cap and wipe around the top of the tube with a clean tissue and carefully decanting the clear solution into a round test tube, filling to the 10 ml mark and adding one Nitricol tablet, crushing and mixing to dissolve, allowing standing for 10 minutes to allow full colour development then selecting Phot 63 for taking the reading and result expressed as mg/l NO3 (Asen *et al.,* 2019).

### 2.3.8 Determination of Chloride

The test tube was filled to the 10 ml mark, and using Phot 46, the Chloride content was measured. Approximately 1 ml of sample was measured into the test tube and made up to the 10ml mark with deionised water. An acidified tablet was added, crushed, and mixed; then a chloridol tablet was added and allowed to stand for 2 minutes to dissolve and settle. A blank sample was used, and the reading was recorded in mg/L (Asen *et al.,* 2019).

### 2.4 Data Analysis

Data collected were analysed using Minitab (17.0) software for descriptive statistics. Inferences were made using the One-way ANOVA and chi-square tests at 95% level of confidence ($P \leq 0.05$). The WHO standard permissible limit served as the reference for each parameter, except where it was not specified.

## 3.0 RESULTS

### 3.1 Physicochemical Properties of Well Water Samples in Wet and Dry Seasons at

### North-Bank Makurdi

Table 2 describes the physicochemical properties of open well water samples at four sampling points in the North bank location (NB-R1 to NB-R4) in the wet season. pH readings ranging from 6.8 to 7.1 fell within the permissible range (6.5-8.5). Electrical conductivity of 0.91-1.13 µs/cm was within the 0.5-1.5 limit. Total dissolved solids varied significantly across sampling points, with a maximum of 252.33 mg/L, which is below the 1000 mg/L permissible level for potable water. Turbidity ranged from 3.25 to 6.23 NTU, with three water samples exceeding the 5 NTU permissible limit. The maximum colour reading obtained (9.23 TCU) was below the 15 TCU limit and varied significantly across sampling points. Total hardness, nitrate, chloride, and carbonate contents were within permissible levels and showed no significant variation among the four water samples.

As shown in Table 3, the results for the dry-season water samples (D1-D4) indicated that only the EC (electrical conductivity) readings of 1.97-2.11 µs/cm exceeded the normal permissible value of 1.5 µs/cm. All other physicochemical parameters were within the normal permissible range for potable water. However, none of the parameters showed significant variation along the sampling points.

**Table 2: Physicochemical Properties of Water Samples in North Bank (Wet Season)**

| Water Sample ID | pH | Temp ($^{O}$C) | EC (µs/cm) | TDS (mg/L) | Turbidity (NTU) | Colour (TCU) | Total Hardness (mg/L) | Nitrate (mg/L) | Chloride (mg/L) | Carbonat (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| **NB-R1** | 6.77 ±0.23 | 24.61 ±0.02 | 0.91 ±0.02 | 163.12 ±4.32$^{c}$ | 3.25 ±0.01$^{c}$ | 4.63 ±0.05$^{c}$ | 33.25 ±0.0$^{5}$b | 5.54 ±0.10 | 6.25 ±0.05 | 17.91 ±0.67 |
| **NB-R2** | 6.56 ± 0.15 | 23.28 ±0.04 | 1.11 ±0.04 | 172.89 ±2.27$^{b}$ | 5.65 ±0.02$^{b}$ | 6.67 ±0.05$^{b}$ | 30.82 ±0.15$^{b}$ | 5.03 ±0.33 | 6.22 ±0.05 | 17.63 ±0.00 |
| **NB-R3** | 7.06 ± 0.20 | 24.36 ±0.05 | 1.02 ±0.01 | 167.43 ±1.16$^{c}$ | 5.56 ±0.05$^{b}$ | 5.29 ±0.05$^{bc}$ | 28.55 ±0.55$^{b}$ | 5.26 ±0.15 | 6.65 ±0.01 | 17.42 ±0.00 |
| **NB-R4** | 7.04 ± 0.15 | 24.19 ±0.03 | 1.13 0.15 | 252.33$^{a}$ ±2.44 | 6.23 ±0.03$^{a}$ | 9.23 ±0.01$^{a}$ | 32.71 ±0.33$^{a}$ | 5.21 ±0.67 | 6.13 ±0.01 | 18.05 ±0.50 |
| WHO PL | **6.5-8.5** | **NS** | **0.5-1.5** | **<1000** | **<5** | **<15** | **NS** | **50** | **<250** | **NS** |
| **P-value** | P>0.05 | P>0.05 | P>0.05 | P<0.05 | P<0.05 | P<0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 |

**Legend:** PL= permissible limit; NS= Not stated; NB = North bank; R1-R4= wet season sample 1-4; EC= electrical conductivity, TDS= total dissolved solid; Temp= temperature

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**Table 3: Physicochemical Properties of Water Samples in North Bank (Dry Season)**

| Water Sample ID | pH | Temp ($^OC$) | EC (µs/cm) | TDS (mg/L) | Turbidity (NTU) | Colour (TCU) | Total Hardness (mg/L) | Nitrate (mg/L) | Chloride (mg/L) | Carbonat (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| NB-D1 | 7.65 ±0.01 | 27.55 ±0.25 | 2.11 ±0.00 | 145.21 ±2.51 | 3.45 ±0.02 | 5.68 ±0.01 | 19.43 ±0.10 | 2.41 ±0.05 | 2.45 ±0.01 | 6.41 ±0.21 |
| NB-D2 | 7.52 ± 0.01 | 28.41 ±0.25 | 1.97 ±0.01 | 141.24 ±3.55 | 4.11 ±0.01 | 6.77 ±0.00 | 21.56 ±0.55 | 2.50 ±0.01 | 2.51 ±0.00 | 7.45 ±0.33 |
| NB-D3 | 7.81 ± 0.03 | 27.55 ±0.33 | 1.99 ±0.02 | 147.65 ±2.22 | 3.88 ±0.03 | 6.01 ±0.02 | 20.17 ±0.25 | 2.33 ±0.00 | 2.39 ±0.00 | 6.81 ±0.15 |
| NB-D4 | 7.88 ± 0.01 | 28.65 ±0.03 | 2.12 0.05 | 145.81 ±1.33 | 3.75 ±0.15 | 5.96 ±0.05 | 21.55 ±0.11 | 2.44 ±0.15 | 2.66 ±0.05 | 6.22 ±0.00 |
| WHO PL | **6.5-8.5** | **NS** | **0.5-1.5** | **<1000** | **<5** | **<15** | **NS** | **50** | **<250** | **NS** |
| P-value | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 |

**Legend:** PL= permissible limit; NS= Not stated; NB = North bank; D1-D4= dry season sample 1-4; EC= electrical conductivity, TDS= total dissolved solid; Temp= temperature

### 3.2 Physicochemical Properties of Well Water Samples in Wet and Dry Seasons at Wadata Makurdi

Table 4 describes the physicochemical properties of open well water samples at four sampling points at Wadata location (WD-R1 to WD-R4) in the wet season. pH readings ranging from 7.2 to 8.2 fell within the permissible range (6.5-8.5). The temperature ranged from 24.4 to 25.5 °C. Electrical conductivity (EC) varied significantly from 1.06 to 2.49 µs/cm. Results showed that EC readings from two sampling points exceeded the 1.5 µs/cm tolerable limit for potable water. Also, the total dissolved solids varied significantly across the sampling points (177.3-264.5 mg/L), but these values were less than the 1000 mg/L permissible level for potable water. Turbidity did not vary significantly; two water samples (WDR3 and WDR4) had turbidity levels≥5.0 NTU, exceeding the permissible limit of <5.0 NTU. All other parameters showed no significant variation among samples. Also, all were found within the acceptable limit for potable water.

In the dry season (Table 5), all physicochemical parameters were found within the normal permissible range for potable water. Significant variability was observed in EC (electrical conductivity) and turbidity readings across sampling points. Results further showed that the WD-D4 sample had the highest values for pH (8.1), TDS (110.5), turbidity (3.76 NTU), total hardness (28.7 mg/L), nitrate (2.3 mg/L), and chloride (2.97 mg/L). However, these values were not significantly different from those in other samples.

**Table 4: Physicochemical Properties of Water Samples in Wadata (Wet Season)**

| Water Sample ID | pH | Temp ($^OC$) | EC (µs/cm) | TDS (mg/L) | Turbidity (NTU) | Colour (TCU) | Total Hardness (mg/L) | Nitrate (mg/L) | Chloride (mg/L) | Carbonat (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| WD-R1 | 8.24 ±0.23 | 25.23 ±0.01 | 1.23 ±0.00[c] | 264.53 ±4.32[a] | 4.53 ±0.01 | 7.13 ±0.01 | 34.30 ±0.22 | 5.21 ±0.00 | 3.96 ±0.02 | 13.50 ±1.50 |
| WD-R2 | 7.17 ± 0.15 | 24.36 ±0.01 | 1.75 ±0.01[b] | 182.19 ±2.27[b] | 4.58 ±0.02 | 6.77 ±0.03 | 33.11 ±0.15 | 4.41 ±0.01 | 4.05 ±0.00 | 15.68 ±0.67 |
| WD-R3 | 8.15 ± 0.20 | 25.45 ±0.00 | 2.40 ±0.05[a] | 262.51 ±1.16[a] | 5.11 ±0.05 | 7.11 ±0.03 | 36.36 ±0.25 | 4.87 ±0.11 | 4.21 ±0.01 | 13.34 ±0.67 |
| WD-R4 | 7.77 ±0.15 | 25.29 ±0.02 | 1.06 0.05[d] | 177.26 ±2.44[b] | 5.01 ±0.03 | 6.94 ±0.00 | 33.21 ±0.51 | 5.00 ±0.11 | 4.02 ±0.00 | 13.80 ±0.23 |
| WHO PL | **6.5-8.5** | **NS** | **0.5-1.5** | **<1000** | **<5** | **<15** | **NS** | **50** | **<250** | **NS** |
| P-value | P>0.05 | P>0.05 | P<0.05 | P<0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 |

**Legend:** PL= permissible limit; NS= Not stated; WD = Wadata; R1-R4= wet season sample 1-4; EC= electrical conductivity, TDS= total dissolved solid; Temp= temperature

**Table 5: Physicochemical Properties of Water Samples in Wadata (Dry Season)**

| Water Sample ID | pH | Temp ($^OC$) | EC (µs/cm) | TDS (mg/L) | Turbidity (NTU) | Colour (TCU) | Total Hardness (mg/L) | Nitrate (mg/L) | Chloride (mg/L) | Carbonat (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| WD-D1 | 7.50 ±0.23 | 28.70 ±0.02 | 0.89 ±0.00[a] | 104.17 ±1.55 | 2.17 ±0.00[b] | 3.75 ±0.01 | 27.41 ±1.55 | 2.16 ±0.01 | 2.76 ±0.06 | 19.65 ±0.55 |
| WD-D2 | 7.31 ± 0.15 | 27.33 ±0.02 | 0.93 ±0.03[a] | 107.65 ±1.50 | 2.12 ±0.01[b] | 3.18 ±0.03 | 29.57 ±0.67 | 2.05 ±0.00 | 2.95 ±0.03 | 19.76 ±0.22 |
| WD-D3 | 7.88 ± 0.20 | 27.73 ±0.03 | 0,62 ±0.01[c] | 105.21 ±3.33 | 2.28 ±0.16[b] | 3.98 ±0.02 | 28.65 ±0.67 | 2.00 ±0.00 | 2.78 ±0.20 | 19.22 ±0.50 |
| WD-D4 | 8.05 ± 0.15 | 28.55 ±0.03 | 0.69 0.02[c] | 110.50 ±2.75 | 3.76 ±0.02[a] | 3.76 ±0.00 | 28.71 ±1.33 | 2.25 ±0.05 | 2.97 ±0.01 | 19.59 ±0.33 |
| WHO PL | **6.5-8.5** | **NS** | **0.5-1.5** | **<1000** | **<5** | **<15** | **NS** | **50** | **<250** | **NS** |
| P-value | P>0.05 | P>0.05 | P<0.05 | P>0.05 | P<0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 |

**Legend:** PL= permissible limit; NS= Not stated; WD = Wadata; D1-D4= dry season sample 1-4; EC= electrical conductivity, TDS= total dissolved solid; Temp= temperature

### 3.3 Physicochemical Properties of Well Water Samples in Wet and Dry Seasons at Gboko Road Makurdi

Table 6 describes the physicochemical properties of open well water samples at four sampling points at Gboko road location (GB-R1 to GB-R4) in the wet season. All parameters were within acceptable ranges for potable water. The maximum temperature reading obtained was 26.7 °C. The following range of readings were obtained for pH (7.57-7.96), EC (1.26-1.34 µs/cm), TDS (121.2-127.4 mg/L), turbidity (3.6-4.6 NTU), colour (4.2-4.3 TCU), total hardness (25.7-29.0 mg/L), chloride (3.2-4.2 mg/L), carbonate (22.4-25.5 mg/L) and nitrate (2.9-6.2 mg/L). Among these, only the differences in nitrate levels were significant in the collected samples.

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In the dry season (Table 7), all physicochemical parameters were within the normal permissible range for potable water, with no significant differences among the values obtained from the water samples. Maximum readings recorded for the following physicochemical properties in the dry season were pH (7.1), temperature (28.9 °C), EC (0.47 µs/cm), TDS (88.7mg/L), turbidity (3.86 NTU), colour (3.1 TCU), total hardness (19.8 mg/L), chloride (2.8 mg/L), carbonate (18.4 mg/L) and nitrate (4.1 mg/L). Unlike in the wet season, nitrate levels in the dry season did not vary among the collected samples.

**Table 6: Physicochemical Properties of Water Samples in Gboko Road (Wet Season)**

| Water Sample ID | Ph | Temp ($^{O}C$) | EC (µs/cm) | TDS (mg/L) | Turbidity (NTU) | Colour (TCU) | Total Hardness (mg/L) | Nitrate (mg/L) | Chloride (mg/L) | Carbonate (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| **GB-R1** | 7.57 ±0.05 | 26.43 ±0.02 | 1.26 ±0.01 | 126.72 ±3.33 | 4.61 ±0.03 | 4.39 ±0.01 | 25.71 ±0.42 | 5.11 ±0.03$^{b}$ | 4.14 ±0.02 | 23.76 ±0.33 |
| **GB-R2** | 7.96 ± 0.01 | 25.72 ±0.03 | 1.33 ±0.01 | 124.62 ±2.55 | 4.62 ±0.03 | 4.29 ±0.01 | 28.98 ±0.02 | 6.21 ±0.50$^{a}$ | 4.23 ±0.01 | 22.37 ±0.33 |
| **GB-R3** | 7.85 ± 0.01 | 26.65 ±0.17 | 1.34 ±0.02 | 121.16 ±1.23 | 3.58 ±0.01 | 4.23 ±0.01 | 26.91 ±0.15 | 4.81 ±0.22$^{c}$ | 3.15 ±0.02 | 25.52 ±0.01 |
| **GB-R4** | 7.71 ± 0.03 | 25.51 ±0.02 | 1.29 0.02 | 127.41 ±1.50 | 3.88 ±0.02 | 4.27 ±0.02 | 28.80 ±0.03 | 2.87 ±0.67$^{d}$ | 4.05 ±0.01 | 25.01 ±0.22 |
| WHO PL | **6.5-8.5** | **NS** | **0.5-1.5** | **<1000** | **<5** | **<15** | **NS** | **50** | **<250** | **NS** |
| **P-value** | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P<0.05 | P>0.05 | P>0.05 |

**Legend:** PL= permissible limit; NS= Not stated; GB = Gboko road; R1-R4= wet season sample 1-4; EC= electrical conductivity, TDS= total dissolved solid; Temp= temperature

**Table 7: Physicochemical Properties of Water Samples in Gboko Road (Dry Season)**

| Water Sample ID | Ph | Temp ($^{O}C$) | EC (µs/cm) | TDS (mg/L) | Turbidity (NTU) | Colour (TCU) | Total Hardness (mg/L) | Nitrate (mg/L) | Chloride (mg/L) | Carbonate (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| **GB-D1** | 6.86 ±0.00 | 28.78 ±0.02 | 0.43 ±0.01 | 84.33 ±2.67 | 3.86 ±0.01 | 2.18 ±0.01 | 18.58 ±0.25 | 3.97 ±0.02 | 2.65 ±0.01 | 17.83 ±0.04 |
| **GB-D2** | 7.11 ± 0.00 | 28.72 ±0.02 | 0.42 ±0.05 | 88.65 ±1.50 | 3.67 ±0.01 | 3.06 ±0.00 | 19.77 ±0.33 | 4.05 ±0.05 | 2.49 ±0.00 | 18.44 ±0.01 |
| **GB-D3** | 6.85 ± 0.05 | 28.65 ±0.11 | 0.47 ±0.00 | 86.38 ±0.67 | 3.55 ±0.03 | 2.77 ±0.03 | 17.80 ±0.20 | 3.99 ±0.00 | 2.84 ±0.01 | 16.98 ±0.03 |
| **GB-D4** | 6.71 ± 0.02 | 28.90 ±0.15 | 0.45 0.00 | 87.27 ±1.33 | 3.83 ±0.00 | 2.98 ±0.01 | 18.11 ±0.01 | 4.11 ±0.00 | 2.65 ±0.00 | 18.36 ±0.00 |
| WHO PL | **6.5-8.5** | **NS** | **0.5-1.5** | **<1000** | **<5** | **<15** | **NS** | **50** | **<250** | **NS** |
| **P-value** | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 |

**Legend:** PL= permissible limit; NS= Not stated; GB = Gboko road; D1-D4= dry season sample 1-4; EC= electrical conductivity, TDS= total dissolved solid; Temp= temperature

### 3.4 Physicochemical Properties of Well Water Samples in Wet and Dry Seasons at Otukpo Road Makurdi

Table 8 describes the physicochemical properties of open well water samples at four sampling points on the Otukpo road axis (OT-R1 to OT-R4) in the wet season. pH readings ranging from 7.2 to 7.9 fell within the permissible range (6.5-8.5). Electrical conductivity (1.07-1.21) µs/cm) was within the 0.5-1.5 limit. Total dissolved solids (TDS) varied significantly across the sampling points, with a recorded maximum value of 200.9 mg/L, but remained below the 1000 mg/L permissible level for potable water. Turbidity varied significantly from 4.63 to 6.75 NTU, with two water samples exceeding the 5 NTU permissible limit. The maximum colour reading obtained (9.85 TCU) was below the 15 TCU limit and varied significantly across sampling points. Total hardness, nitrate, chloride, and carbonate contents were within permissible levels and showed no significant variation among the four water samples.

As shown in Table 9, the results for the dry-season water samples (D1-D4) indicated that only the EC (electrical conductivity) readings of 0.13-0.47 µs/cm were outside the normal permissible range for drinking water (0.5-1.5 µs/cm). All other physicochemical parameters were normal. Significant differences were observed in EC (0.13-0.47 µs/cm), TDS (70.4-99.7 mg/L) and turbidity (1.9-3,8 NTU)

**Table 8: Physicochemical Properties of Water Samples in Otukpo Road (Wet Season)**

| Water Sample ID | pH | Temp ($^{O}C$) | EC (µs/cm) | TDS (mg/L) | Turbidity (NTU) | Colour (TCU) | Total Hardness (mg/L) | Nitrate (mg/L) | Chloride (mg/L) | Carbonat (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| OT-R1 | 7.88 ±0.00 | 23.11 ±0.67 | 1.17 ±0.01 | 209.85 ±3.76$^{a}$ | 6.75 ±0.00$^{a}$ | 9.85 ±0.00$^{a}$ | 36.11 ±0.17 | 7.23 ±0.03 | 5.23 ±0.05 | 28.31 ±0.25 |
| OT-R2 | 7.73 ± 0.02 | 25.19 ±0.00 | 1.21 ±0.02 | 175.84 ±4.45$^{b}$ | 4.98 ±0.01$^{c}$ | 4.99 ±0.00$^{b}$ | 39.57 ±0.15 | 7.18 ±0.67 | 4.64 ±0.33 | 26.18 ±0.33 |
| OT-R3 | 7.79 ± 0.03 | 24.75 ±0.07 | 1.15 ±0.02 | 200.53 ±3.33$^{a}$ | 6.05 ±0.02$^{b}$ | 8.81 ±0.00$^{a}$ | 37.05 ±0.67 | 7.13 ±0.22 | 5.87 ±0.67 | 21.42 ±0.67 |
| OI-R4 | 7.21 ± 0.01 | 23.08 ±0.02 | 1.07 ±0.02 | 174.96 ±4.40$^{b}$ | 4.63 ±0.02$^{c}$ | 4.96 ±0.04$^{b}$ | 36.67 ±0.67 | 7.19 ±0.15 | 5.31 ±0.01 | 20.77 ±0.33 |
| WHO PL | **6.5-8.5** | **NS** | **0.5-1.5** | **<1000** | **<5** | **<15** | **NS** | **50** | **<250** | **NS** |
| P-value | P>0.05 | P>0.05 | P>0.05 | P<0.05 | P<0.05 | P<0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 |

**Legend:** PL= permissible limit; NS= Not stated; OT = Otukpo road; R1-R4= wet season sample 1-4; EC= electrical conductivity, TDS= total dissolved solid; Temp= temperature

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**Table 9: Physicochemical Properties of Water Samples in Otukpo (Dry Season)**

| Water Sample ID | Ph | Temp ($^{O}$C) | EC (µs/cm) | TDS (mg/L) | Turbidity (NTU) | Colour (TCU) | Total Hardness (mg/L) | Nitrate (mg/L) | Chloride (mg/L) | Carbonate (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| **OT-D1** | 8.02 ±0.03 | 27.32 ±0.33 | 0.13 ±0.00$^{d}$ | 70.41 ±1.67$^{c}$ | 2.77 ±0.02$^{b}$ | 2.31 ±0.01 | 19.78 ±0.25 | 3.17 ±0.00 | 5.46 ±0.01 | 21.96 ±0.15 |
| **OT-D2** | 7.95 ± 0.01 | 28.55 ±0.15 | 0.24 ±0.010$^{c}$ | 75.28 ±1.15$^{c}$ | 1.89 ±0.05$^{c}$ | 2.64 ±0.01 | 22.66 ±0.11 | 3.33 ±0.05 | 5.77 ±0.05 | 17.44 ±0.56 |
| **OT-D3** | 8.04 ± 0.00 | 28.91 ±0.22 | 0.47 ±0.01$^{a}$ | 99.67 ±2.52$^{a}$ | 3.81 ±0.01$^{a}$ | 2.55 ±0.05 | 20.75 ±0.33 | 4.59 ±0.07 | 5.66 ±0.05 | 19.33 ±0.33 |
| **OT-D4** | 7.98 ± 0.02 | 27.75 ±0.33 | 0.32 ±0.02$^{b}$ | 89.16 ±2.87$^{b}$ | 2.52 ±0.01$^{b}$ | 2.58 ±0.05 | 19.33 ±0.22 | 3.19 ±0.15 | 5.79 ±0.02 | 22.53 ±0.67 |
| WHO PL | **6.5-8.5** | **NS** | **0.5-1.5** | **<1000** | **<5** | **<15** | **NS** | **50** | **<250** | **NS** |
| **P-value** | P>0.05 | P>0.05 | P<0.05 | P<0.05 | P<0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 | P>0.05 |

**Legend:** PL= permissible limit; NS= Not stated; OT = Otukpo road; D1-D4= dry season sample 1-4; EC= electrical conductivity, TDS= total dissolved solid; Temp= temperature

### 3.5 Variation in Physicochemical Properties across Sampling Locations and Seasons

Variation in hydrogen ion concentration (pH) in water samples collected (Figure 2) shows that Wadata well water samples had higher pH values (slightly alkaline) than other samples in the wet season. In comparison, Otukpo road samples had higher pH values than other samples in the dry season. The mean difference in pH readings in the two seasons was insignificant ($t = 0.24$, $p > 0.05$) as shown in Figure 3, where pH >7.0 <8.0. Variation in the temperature profiles of water samples (Figure 4) shows that Gboko road well water samples had higher temperatures than other samples in the wet season. At the same time, the readings fluctuated slightly among locations in the dry season. Results showed that the dry-season mean temperature (< 25 °C) was significantly higher than the wet-season mean temperature (> 28 °C; $t = 11.16$, $p < 0.05$), as shown in Figure 5.

Variation in electrical conductivity (EC) of water samples collected (Figure 6) shows that two well water sources at Wadata had higher EC values than other samples in the wet season. In contrast, North bank well water samples had higher readings than other samples in the dry season. The mean difference in EC readings in the two seasons was insignificant ($t = 1.78$, $p > 0.05$) as shown in Figure 7, where EC >0.5<1.5 Variation in total dissolved solids (TDS) of water samples (Figure 8) shows that three well water sources at Wadata and one sample at Northbank had higher TDS values than other samples in the wet season. All the water samples collected on the North bank during the dry season had higher TDS than those collected elsewhere. The mean difference in TDS readings between the two seasons was significant ($t = 5.65$, $p < 0.05$), as shown in Figure 9, where TDS was significantly higher in wet-season samples than in dry-season samples.

Variation in turbidity of water samples (Figure 10) shows that three well water sources at Otukpo road and North bank were more turbid than other samples in the wet season. This property varied across locations during the dry season. The mean difference in turbidity levels between the two seasons was significant ($t = 5.64$, $p < 0.05$), as shown in Figure 11, where wet-season samples were more turbid than dry-season samples. Variation in total hardness of water samples (Figure 12) shows that hardness was lowest in samples collected from the Gboko road axis in both seasons. This property fluctuated in the wet season across locations where water samples from Otukpo road, Wadata and North bank were hard water. In the dry season, Wadata water samples were harder than other samples from other locations. The mean difference in total hardness of water between the two seasons was significant ($t = 7.39$, $p < 0.05$), as shown in Figure 13, where wet-season samples were harder than dry-season samples. Variation in nitrate levels of water samples (Figure 14) shows that well water sources on Otukpo road had higher nitrate content than other sources in the wet season. In comparison, water samples collected from Gboko road and Otukpo road had higher nitrate content than those from the other roads in the dry season. The mean difference in nitrate level in the two seasons was significant ($t = 6.68$, $p < 0.05$), as shown in Figure 15, where wet season samples contained higher nitrate contents than dry season samples.

Variation in the chloride level of water samples (Figure 16) shows that well water sources from Northbank and Otukpo road contained higher chloride content than other sources in the wet season. In comparison, water samples collected from Otukpo road had higher chloride content than those from the other sites in the dry season. The mean difference in chloride level in the two seasons was significant ($t = 3.39$, $p < 0.05$), as shown in Figure 17, where wet season samples contained higher chloride contents than dry season samples. Variation in carbonate levels of water samples (Figure 18) shows that well water sources from Gboko road and Otukpo road had higher carbonate content than other sources in the wet season. In contrast, all water samples, except the Northbank samples, were rich in carbonates. The mean difference in carbonate level in the two seasons was significant ($t = 2{,}08$, $p < 0.05$), as shown in Figure 19, where wet season samples contained higher carbonate contents than dry season samples.

## 4.0 DISCUSSION

Open wells in Makurdi metropolis are hand-dug, uncovered sources that many households depend on for drinking water. Because they lack protective covers, they are directly exposed to environmental and anthropogenic inputs. This study evaluated seasonal variation in the physicochemical quality of water from these wells and assessed the implications for water quality and human health. Most physicochemical parameters measured across both wet and dry seasons fell within WHO guideline values for drinking water. However, the data reveal clear seasonal patterns and localised risks. During the wet season, several parameters, including turbidity, electrical conductivity, total hardness, colour, nitrate, chloride, and

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carbonate, showed significant increases. This is likely driven by surface runoff carrying waste, soil particles, agrochemicals, and other pollutants directly into uncovered wells. Many of the wells are shallow and fill to the brim during rains, increasing vulnerability to contamination. Flooding, agricultural activities, and poor sanitation around wells in Northbank, Wadata, and Otukpo Road further amplified these effects, consistent with reports by Asen *et al*. 2019 and Shar *et al*. 2021

In contrast, dry-season water showed greater stability across most parameters. High daily withdrawal rates lead to rapid water turnover, and subsurface inflow through preferential channels may introduce less-contaminated groundwater. This natural "flushing" and dilution may explain why many parameters remained stable despite the lack of covers, a pattern also observed in closed wells by Rahmanian *et al*. 2011 and Tanium *et al*. 2011. Temperature was the only parameter higher in the dry season, reflecting direct exposure to sunlight and higher ambient temperatures, as described by Echebima, S.I. and Obafemi, A.A. (2023). While average values appeared acceptable, site-specific issues are concerning. Only wells along Gboko Road maintained stable physicochemical properties in both seasons. At Northbank, Wadata, and Otukpo Road, turbidity exceeded the WHO limit of 5 NTU, reaching 6.23 NTU and 6.75 NTU, respectively. Electrical conductivity at Northbank also rose above the recommended 0.5–1.5 µS/cm range. Elevated turbidity and TDS are linked to suspended sediments and organic matter from runoff and surrounding waste, which reduce aesthetic quality and can shield pathogens from disinfection. Total hardness in nearby studies has been reported to reach up to 567 mg/L, well above the SON threshold of 150 mg/L, indicating localised geological and anthropogenic influences.

PH values were slightly alkaline (>7.0) but within acceptable limits. Alkalinity can indicate contamination from carbonate rocks or leaching from waste. Nitrate levels were generally within limits but spiked at some sites, likely from fertiliser use. This poses a direct health risk: nitrate >50 mg/L can cause methemoglobinemia in infants under 6 months. High chloride and carbonate levels may reflect both bedrock geology and seasonal infiltration, and prolonged intake has been linked to endocrine disruption and dental problems in children. From a human health perspective, the findings show a paradox. While most physicochemical parameters meet WHO standards on average, seasonal spikes and site-specific contamination in uncovered wells increase the risk of exposure, especially during the rainy season, when water demand is high. Natural attenuation processes help moderate some parameters, but they cannot remove microbial pathogens or prevent chemical inputs from surface runoff. In summary, seasonal variation strongly influences the physicochemical quality of open well water in Makurdi. The wet season poses a higher risk of contamination, while the dry season offers relative stability due to dilution. Protecting public health will require low-cost, community-based interventions: installing sanitary covers, sealing wellheads, relocating wells away from waste dumps, and conducting regular water quality monitoring. Without these measures, the benefits of natural purification will remain insufficient to guarantee safe drinking water year-round.

## 5. CONCLUSION

This study demonstrates that while most physicochemical parameters in Makurdi's open well waters meet WHO and Nigerian drinking water standards, localised and seasonal exceedances present real water-quality and public health concerns. Turbidity and electrical conductivity emerged as the most critical parameters. Turbidity exceeded the WHO guideline of 5 NTU at Northbank, Wadata, and Otukpo Road, while electrical conductivity fell outside the recommended 0.5–1.5 µS/cm range at multiple locations. Seasonality played a decisive role. Wet-season conditions consistently elevated most parameter values compared to the dry season, except for pH and electrical conductivity, which remained stable. This reflects the vulnerability of shallow, uncovered wells to rainfall-driven runoff, dilution, and contaminant mobilisation. The clear spatial and temporal variability also shows that single-point sampling is insufficient to assess groundwater safety. Continuous, seasonally stratified monitoring is essential to capture true exposure risks. Overall, reliance on untreated water from open wells in Makurdi Metropolis carries an elevated risk of exposure to aesthetic and potentially pathogenic contaminants, particularly during peak rainfall. While natural dilution and high withdrawal rates help stabilise certain parameters during the dry season, they cannot replace protective measures. Installing sanitary covers, sealing well heads, and implementing regular community-based monitoring are urgent, low-cost steps needed to safeguard the health of households that depend on these wells.

## 6. RECOMMENDATION

The findings of this study indicate that while open well water in Makurdi largely complies with WHO and Nigerian drinking water standards, seasonal and localised exceedances introduce measurable risks to water quality and public health. During the dry season, frequent withdrawal and natural dilution contribute to the relative stability of most physicochemical parameters. In contrast, wet season conditions consistently elevate turbidity, electrical conductivity, and other contaminant indicators due to rainfall-driven runoff into shallow, unprotected wells. These patterns underscore the need for integrated, seasonally responsive interventions that address both point-of-use risks and source vulnerability.

At the household level, consistent point-of-use treatment should be promoted among communities reliant on open wells. Boiling, filtration, and chemical disinfection remain effective, low-cost strategies for reducing microbial and physicochemical contaminant loads prior to consumption. Because contamination intensifies during the rainy season, public health authorities should prioritise targeted advisories, the seasonal distribution of affordable disinfectants, and practical demonstrations of treatment methods from May to October, when hydrological conditions most favour the mobilisation of contaminants. Infrastructure improvements are equally critical. All open wells should be upgraded with sanitary seals and protective covers to prevent direct ingress of surface water, debris, and anthropogenic pollutants. This intervention addresses the primary pathway for seasonal contamination and offers a more sustainable solution than reliance on post-collection treatment alone.

Water quality surveillance must also be strengthened. Single-point sampling is inadequate for capturing the temporal variability demonstrated in this study. Regulatory agencies should institutionalise routine, seasonally stratified monitoring of unprotected groundwater sources, with increased sampling frequency during the wet season. Monitoring data should be integrated into community water safety programs to ensure that residents receive timely information on water quality and appropriate risk-reduction measures.

Finally, long-term protection of groundwater resources requires improved source water management. Anthropogenic activities that increase contaminant loading during the wet season, including improper solid waste disposal, open defecation near well sites, and unregulated agricultural runoff, must be regulated through enforceable sanitation and land-use policies. Complementary public education campaigns should focus on safe water handling, storage in clean covered containers, and basic hygiene practices to reduce post-collection contamination.

Collectively, these measures can reduce exposure risks, improve the safety of drinking water from open wells, and advance progress toward Sustainable Development Goal 6. In rapidly urbanising settings such as Makurdi, achieving safe water security will depend on combining low-cost engineering solutions, consistent seasonal monitoring, and community engagement in water resource protection.

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