

## ORIGINAL RESEARCH ARTICLE

## Hydrochemical Evaluations and Public Health Implications of Borehole Water in an Internally Displaced Persons Camp, Maiduguri, Nigeria

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### ABSTRACT

This study evaluated seasonal differences in physicochemical parameters and the Water Quality Index (WQI) of borehole water used by IDPs in the FTC Camp, Maiduguri, during the wet and dry seasons to determine its suitability for consumption. A structured questionnaire was used to obtain socio-demographic data. Water samples were collected from 4 boreholes at the FTC camp 3 times in the wet and dry seasons. During the wet and dry seasons, temperature, colour, pH, turbidity, major and trace metals, and dissolved constituents were determined using standard analytical procedures. Important parameters such as pH,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{Cu}^{2+}$ ,  $\text{Cr}^{3+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{F}^-$ , and  $\text{Zn}^{2+}$  were weighted according to the 2007 Nigerian Industrial Standards for Water Quality. High weights were assigned to trace ions and nutrients due to their potential toxicity. The concentrations of the parameters were described by season using descriptive statistics. IDPs are mainly female, young, and less educated, with large household sizes. These attributes outline the key weaknesses that need to be addressed with a humanitarian focus. Some important parameters include temperature: 21.60°C (wet season), 25.03°C (dry season); pH 6.95-7.26; TDS 101.00-219.75 mg/l; and trace metals, all within the acceptable range. All the physicochemical parameters had seasonal changes. The WQI values were 26.30 (wet season) and 31.65 (dry season), indicating that the water is not suitable for domestic use, as reported in past literature for some areas of Maiduguri. The physicochemical findings suggest that the borehole water is basically safe for consumption. The WQI is poor, implying that the vulnerable IDPs could be at risk. It is strongly advised to regularly monitor, provide treatment, and include health risk assessment (HQ, HI, HPI) to protect public health.

### ARTICLE HISTORY

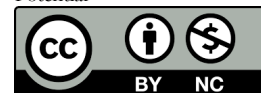
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### KEYWORDS

Physicochemical parameters, Water Quality Index, Concentration, Socio-demographic data, Toxicity Potential



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### INTRODUCTION

Water is the primary natural resource. Scholars have also confirmed that it is the most essential substance on Earth for sustaining human life and economic activities (Issa, 2017; Saleh *et al.*, 2025). The availability of water in sufficient amounts, with the right quality and quantity, is necessary for life and other uses (Khwakaram *et al.*, 2012). Fresh water is a vital resource across various aspects of human life (Mishra and Dubey, 2023), significantly supporting human activity and driving economic growth. Beyond drinking, water resources are crucial for many economic sectors, including agriculture, forestry, livestock production, industry, hydropower, fisheries, and other pursuits (Sivaranjani *et al.*, 2015). Factors such as population growth, industrialization, and urbanization have led to declines in surface and groundwater quality and quantity. Water contamination from various sources has become a major environmental issue, negatively affecting both the economy and human health. This

deterioration of water quality creates unfavourable conditions that hinder its use for recreation, swimming, and as a raw water source (Sivaranjani *et al.*, 2015; Kumar *et al.*, 2024).

Most frequently, polluted water sources may contain toxic substances and free radicals that can lead to undesirable health outcomes, genetic mutations, and chronic diseases (Wadhwa *et al.*, 2012; Badamasi and Salisu, 2025). The over the years reduced quality of freshwater has been blamed on concentrated human activities such as intensive farming, urbanization, and industrialization. Such forces have led to a decline in water quality in rivers, lakes, and groundwater systems across most areas (Puri *et al.*, 2015). With increased recognition of the significance of water quality to aquatic life and human health, there has been an urgent need to evaluate and track water resources (Ali and Ghareeb, 2023).

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Knowledge of the hydro-geochemical properties of water plays a critical role in determining its suitability for domestic, agricultural, and industrial use. The above-mentioned properties are shaped by either natural processes of interaction between water and the geological structures of the streams it runs in or human-made pollution (Imad and Shuokr, 2020). In assisting in making effective decisions, tools such as the Water Quality Index (WQI) have been developed to facilitate detailed yet easy measurements of drinking water quality. The WQI helps water managers and communities assess water quality by combining many physicochemical measures into a single value that is easy to read (Chidiac et al., 2023).

With this background in mind, this study aims to investigate the water quality characteristics of internally displaced people in the FTC camp in Maiduguri, Borno State, Nigeria. The objective of the research is to investigate the physicochemical characteristics of water quality for internally displaced people in the FTC camp in Maiduguri, Borno State, Nigeria, and to propose potential strategies to enhance water quality for these individuals.

The study is justified by the fact that the water-quality studies in Nigeria are often conducted under the conditions of low vulnerability in addition to the fact that IDP camps have a higher vulnerability. It expands on the current literature by combining a seasonal WQI study with socio-demographic profiling and suggesting health-risk examination, which is rarely found in humanitarian contexts.

**METHODOLOGY**

**Study Area:** The state of Borno is located in northeastern Nigeria (Mohammed, 2014), and its capital, Maiduguri, has a population of approximately 4,171,104 (NPC, 2006) and 1,907,600 as of 2007 (Zhukovskii, 2016). The IDP camp at FTC Maiduguri is located on latitude **11.77871° N, and longitude 13.22430° E.** (IOM, 2025) The majority of the population is Muslim and is divided into the tribes of Kanuri, Shuwa, Bura, Marghi, and Fulani, with a small number of migrants from other parts of the country.

**Sampling Procedure and Sample Size**

Four distinct borehole sources in the FTC camp in Maiduguri provided samples of water, and a laboratory experiment was conducted using a few indicators to determine the water's quality. The laboratory experiment was used to gather data on the physicochemical characteristics of the water used by the FTC Internally Displaced Persons (IDPs), including average temperature, turbidity, colour, and electrical conductivity.

To summarise the demographic characteristics of the 100 IDPs selected at the FTC in Maiduguri, a simple random sampling technique was employed.

**Method of Data Collection:** Samples of water from 4 different boreholes in FTC Camp, Maiduguri were

collected 3 times in the wet and dry seasons (at the beginning, peak, and end of each season).

The following descriptive statistics were used to describe the physicochemical parameters: temperature, colour, turbidity, pH, electrical conductivity, sodium, carbonate, bicarbonate, magnesium hardness, total Hardness, copper, iron, manganese, phosphate, chromium, chloride, sulphate, nitrate, nitrite, fluoride, zinc, potassium, *Escherichia coli*, and total coliform count: minimum value, maximum value, mean, and standard deviation.

**Method of Data Analysis**

The socioeconomic characteristics of the IDPs in the FTC camp in Maiduguri were recorded using descriptive statistics including frequency, mean, and percentage distribution. Gender, education, age, and household size are some examples of these socioeconomic traits.

The WQI for the four boreholes in the FTC camp, Maiduguri, was assessed using seasonal measurements of parameter weights (wi), relative weights (Wi), concentrations (Ci), standards (Si), quality ratings (qi), sub-indices (SI), and effective weights (Ewi). These computations enabled a comprehensive evaluation of wet- and dry-season water quality for internally displaced persons in the camp. The WQI of the IDPs at the FTC camp in Maiduguri was evaluated as follows:

Assigned weight to parameters – wi

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i} \dots\dots\dots(1)$$

Where, Wi = relative weight

n = number of parameters

$$q_i = \frac{C_i}{S_i} \times 100 \dots\dots\dots(2)$$

qi = is the quality rating

Ci = is the concentration of each chemical parameter in each water sample in mg/L

Si = is the standard for each chemical parameter in mg/L

$$SI_i = W_i \times q_i \dots\dots\dots(3)$$

Where, SIi = is the sub-index of the ith parameter

$$WQI = \sum SI_i \dots\dots\dots(4)$$

The quality of water index is done as excellent (for index range >80-100), good (for index range >60-80), moderate (for index range >40-60), bad (for index range >20-60) and very bad (for index range >0-20) as was also adopted by Swamee and Tyagi, (2007).

The Heavy Metal Pollution Index (HPI) is a measure of the safety of drinking groundwater contaminated with metals. *Kyowe et al., (2024)* estimated as follows:

$$\text{Sub index} = \sum \left( \frac{\text{Average Concentration of Metal}}{\text{Standard}} \right) \dots\dots\dots (5)$$

Determining Unit Weightage

$$\text{Proportionality constant} = \sum (1/ \text{Standaard for heavy metal}) \dots\dots\dots (6)$$

$$K = 1/\sum (1/ \text{Standaard for heavy metals}) \dots\dots\dots (7)$$

Unit Weightage of Metal = k/Standard for heavy metal

$$\text{HPI} = \sum (\text{Unit Weightage of Metal} * \text{Sub Index of Metal}) \dots\dots\dots(8)$$

HPI < 100: Low Pollution, that is, water is safe with respect to heavy metals

HPI = 100: Critical Limit, that is, the threshold for drinking water

HPI > 100: High Pollution, that is, water is contaminated and unsuitable for drinking without treatment

$$\text{HI} = \text{HQ}_{\text{Cr}} + \text{HQ}_{\text{Mn}} \dots\dots\dots (9)$$

HI = Hazard index

HQ = Hazard quotient

**RESULTS AND DISCUSSION**

The socio-economic characteristics in [Table 1](#) describe the demographic attributes of IDPs in the FTC camp, Maiduguri, and reveal that the majority (65.0%) of the IDPs were female; this is similar to findings by [Abubakar \(2024\)](#), who argued that women make up most of the IDP population. The study reveals that most (65.0%) of the IDPs in the FTC camp, Maiduguri, had never attended school, while about 5.0% of the IDPs dropped out of school; this statistic suggests that the level of illiteracy in the study area is not only high but it is also critical and needs urgent attention as corroborated by [Jacob, \(2023\)](#). [Table 1](#) showed that most of the IDPs (59.0%) were youths in the age bracket of 21 and 40 years with a mean age of 36 years; this is consistent with the submission by [UNHCR \(2021\)](#). It was also discovered that 37% of the IDPs in the FTC camp had a household size of between 4 and 6, while a few (2.0%) of the respondents had a household size of between 13 and 15, and the average household size of the respondents was 6; this was corroborated by [Tafida et al. \(2023\)](#).

**Table 1: Distribution of IDPs by Socio-economic Characteristics**

Characteristics	Frequency	Mean	Percentage
<b>Gender</b>			
Male	35.0		35.00
Female	65.0		65.00
Total	100.00		100.00
<b>Education Level</b>			
Primary School	20.0		20.00
Secondary School	10.0		10.00
Dropout	5.0		5.00
Never Attended School	65.0		65.00
Total	100.00		100.00
<b>Age (years)</b>			
≤ 20	6.0		6.00
21-40	59.0		59.00
41-60	32.0		32.00
≥61	3.0		3.00
Total	100.00		100.00
<b>Household Size</b>			
1- 3	28.0		28.00
4- 6	37.0		37.00
7- 9	24.0		24.00
10 - 12	9.0		9.00
13 - 15	2.0		2.00
Total	100.00	6.00	100.00

Source: Field Survey (2024)

**Physicochemical Properties of the IDPs Source of Water at FTC Camp Maiduguri:**

[Table 2](#) presents the concentrations of the principal physicochemical parameters of the borehole water

sampled by IDPs in the FTC camp, Maiduguri, during the wet and dry seasons. The seasonal change in temperature revealed that the average water temperature was 21.60°C during the wet season and rose to 25.03°C during the dry season. This finding was similar to that of [Şener et al.](#)

(2017). Recorded water colour in the wet period (14.75 Pt/Co) was higher than in the dry period (3.00 Pt/Co), probably because organic and inorganic debris are transported by rainwater runoff, as suggested by Adedeji (2017). Turbidity, affected by algae and suspended particulates from runoff or sediment disturbance, had means of 1.60 NTU during the wet season and 2.50 NTU during the dry season (Gorde and Jadhav, 2013).

Water pH is an important factor for assessing the acidic or basic nature of water, it also tells how soluble metals are, how hard they are, and how alkaline they are (Mshelia *et al.*, 2023). The average pH levels were 6.95 in the wet season and 7.26 in the dry season, which implies that the borehole water was safe to drink and use for domestic purposes. Total dissolved solids (TDS), which are dissolved organic and inorganic substances (Corwin and Yemoto, 2017), increased from 101.00 mg/l in the wet season to 219.75 mg/l in the dry season. Figure 1 shows that inter-seasonal variation exists in some parameters, such as temperature and TDS. Electrical conductivity (EC), which shows ionic concentration, had average values of 201.75  $\mu\text{S}/\text{cm}$  in the wet season and 196.75  $\mu\text{S}/\text{cm}$  in the dry season. Both *E. coli* and total coliform count were 0.00 CFU. This suggests the absence of pathogens (Sanderson *et al.*, 2005).

The concentration of sodium ions ( $\text{Na}^+$ ) was quite steady, with average values of 37.00 mg/L (in the wet season) and 38.75 mg/L (in the dry season). The concentration of carbonate ion ( $\text{CO}_3^{2-}$ ) was low, at 4.50 mg/L in the wet season and 4.75 mg/L in the dry season. The amount of bicarbonate ion ( $\text{HCO}_3^-$ ) decreased from 88.55 mg/L in the wet season to 85.98 mg/L in the dry season. These results suggest that there are not many carbonate-rich geological formations in the area, such as crystalline limestone, dolomitic limestone, calcgranulite, and kankar. This differs from the previous submission by Şener *et al.* (2017).

The concentration of magnesium ion ( $\text{Mg}^{2+}$ ) was 2.47 mg/l in the wet season and 2.36 mg/l in the dry season. In the wet season, total Hardness was 2.47 mg/L, but it increased significantly to 67.75 mg/L in the dry season. The minor and trace metals ( $\text{Mn}^{2+}$ ,  $\text{PO}_4^{3-}$ ,  $\text{Cu}^{2+}$ ,  $\text{Cr}^{3+}$ , and  $\text{Zn}^{2+}$ ), which Matthew and Krishnamurthy (2014) identified, were present in low concentrations. The average seasonal concentration of  $\text{Mn}^{2+}$  was 0.25 mg/l in the wet season and 0.12 mg/l in the dry season. The average concentration of  $\text{PO}_4^{3-}$  was 2.99 mg/l in the wet season and 2.82 mg/l in the dry season, consistent with past findings by Yohanna (2022). The concentration of copper ( $\text{Cu}^{2+}$ ) increased from 0.02 mg/l in the wet season to 0.23 mg/l in the dry season. The average concentration of chromium ions ( $\text{Cr}^{3+}$ ) was 0.01 mg/l in the wet season and 0.02 mg/l in the dry season. The average concentration of zinc ions ( $\text{Zn}^{2+}$ ) was 0.16 mg/l in the wet season and 0.13 mg/l in the dry season. The trace metal distributions reported by Injin *et al.* (2024) are consistent with these data. Al-Khashman (2007) suggested that these

trace metals may be present in groundwater due to natural geochemical processes or human activity.

Chloride ( $\text{Cl}^-$ ) and sulphate ( $\text{SO}_4^{2-}$ ) are two of the most important dissolved substances (Matthew and Krishnamurthy, 2014). Their average concentrations during the wet season were 9.00 mg/L and 14.00 mg/L, respectively. In the dry season, these concentrations rose to 14.25 mg/l and 19.75 mg/l, respectively. These results are similar to those published by Mshelia *et al.* (2023). The secondary dissolved constituents ( $\text{Fe}^{2+}$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{F}^-$ , and  $\text{K}^+$ ) also varied from season to season. The average concentrations of  $\text{Fe}^{2+}$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{F}^-$ , and  $\text{K}^+$  in the wet season were 0.07 mg/l, 0.83 mg/l, 0.01 mg/l, 0.44 mg/l, and 29.75 mg/l respectively. In the dry season, the average amounts were 0.16 mg/l, 0.92 mg/l, 0.14 mg/l, 0.32 mg/l, and 28.50 mg/l, respectively. These findings are similar to those of Şener *et al.* (2017). Figure 2 reveals that inter-seasonal variation also exists between some of the ionic parameters, such as  $\text{Mn}^{2+}$ ,  $\text{NO}_3^-$ ,  $\text{PO}_4^{3-}$

Although previous literature on water resources in Maiduguri and Northeast Nigeria has generally concentrated on the groundwater quality in cities, rural community water points, or water pollution gradients at municipal levels (Ocheri *et al.*, 2014; Jidda *et al.*, 2025), this study specifically examined water supplied to Internally Displaced Persons (IDPs) as it bothers on the quality of water and the public health implications of borehole water.

### Water Quality Index of Water Supplied to IDPs at FTC Camp Maiduguri

The FTC camp boreholes were assessed during the wet and dry seasons using a multi-step process to determine Water Quality Index (WQI). All water quality parameters were assigned weights based on their relative importance to drinking water, according to the 2007 Nigerian Standards of Water Quality, as shown in Table 3. These parameters include: pH,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{Cu}^{2+}$ ,  $\text{Cr}^{3+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{F}^-$ , and  $\text{Zn}^{2+}$ . Trace ions and nutrients were assigned a maximum weight of 5, since they significantly affect water quality and are potentially toxic when present in high concentrations, as observed in previous studies (Şener *et al.*, 2017). Nitrate and nitrite, which are hazardous to health irrespective of age and gender, were also highly weighted (Varol and Davraz, 2015; Şener *et al.*, 2017). The weights for parameters like pH and  $\text{SO}_4^{2-}$  were 4, and those for  $\text{Cl}^-$ ,  $\text{Fe}^{2+}$  and  $\text{F}^-$  were 3.  $\text{Mg}^{2+}$  and  $\text{Na}^+$ , which are considered not very important to the overall quality of water, received the lowest weight of 2. The WQI calculated in the wet season was 26.30 and in the dry season was 31.65, which implies that the borehole water distributed to IDPs is not safe and unsuitable for domestic use, considering that the WQI were lesser than 90.00 in both seasons; similar results were reported in Old Maiduguri axis (Mshelia *et al.*, 2023). Figure 3 reveals the inter-seasonal variation in the WQI between the wet and dry seasons.

**Table 2: Statistical Summary of Physicochemical Parameters of Borehole Water**

Parameters	Wet Season				Dry Season			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Temperature (°C)	19.3	23.3	21.6	1.764	24.3	25.3	25.025	0.486
Colour (Pt/Co)	0	53	14.75	25.591	0	6	3	2.944
Turbidity (NTU)	0.311	4.82	1.602	2.151	1	4	2.5	1.291
pH	6.8	7	6.95	0.1	6.9	7.66	7.263	0.325
TDS (mg/l)	97	104	101	3.559	104	320	219.75	111.326
Electrical Conductivity (µS/cm)	193	208	201.75	7.5	190	208	196.75	8.617
Sodium (mg/l)	34	39	37	2.16	37	42	38.75	2.363
Carbonate (mg/l)	3	6	4.5	1.291	3	7	4.75	1.708
Bicarbonate (mg/l)	73.4	97.9	88.55	11.789	73.4	92.9	85.975	9.146
Magnesium Hardness(mg/l)	2.24	2.55	2.468	0.152	2.24	2.55	2.36	0.133
Total Hardness (mg/l)	2.24	2.55	2.468	0.152	48	81	67.75	14.009
Copper (mg/l)	0.01	0.03	0.02	0.012	0.12	0.35	0.228	0.1103
Iron (mg/l)	0.02	0.13	0.073	0.0556	0.1	0.19	0.158	0.0423
Manganese (mg/l)	0.1	0.4	0.25	0.129	0.02	0.18	0.123	0.071
Phosphate (mg/l)	2.77	3.31	2.988	0.265	2.11	3.31	2.823	0.524
Chromium (mg/l)	0.002	0.013	0.006	0.005	0.01	0.03	0.02	0.008
Chloride (mg/l)	6	12	9	3.464	13	17	14.25	1.893
Sulphate (mg/l)	10	18	14	4.619	12	28	19.75	8.421
Nitrate (mg/l)	0.6	1	0.825	0.171	0.41	1.28	0.915	0.428
Nitrite (mg/l)	0.005	0.006	0.006	0.001	0.07	0.14	0.103	0.033
Fluoride (mg/l)	0.27	0.57	0.435	0.126	0.1	0.49	0.318	0.198
Zinc (mg/l)	0.073	0.25	0.158	0.078	0.1	0.18	0.13	0.356
Potassium (mg/l)	24	35	29.75	5.56	24	35	28.5	4.796
E. Coli (CFU)	0	0	0	0	0	0	0	0
Total Coliform Count (CFU)	0	0	0	0	0	0	0	0

Source: Field Survey (2024); SD = Standard Deviation

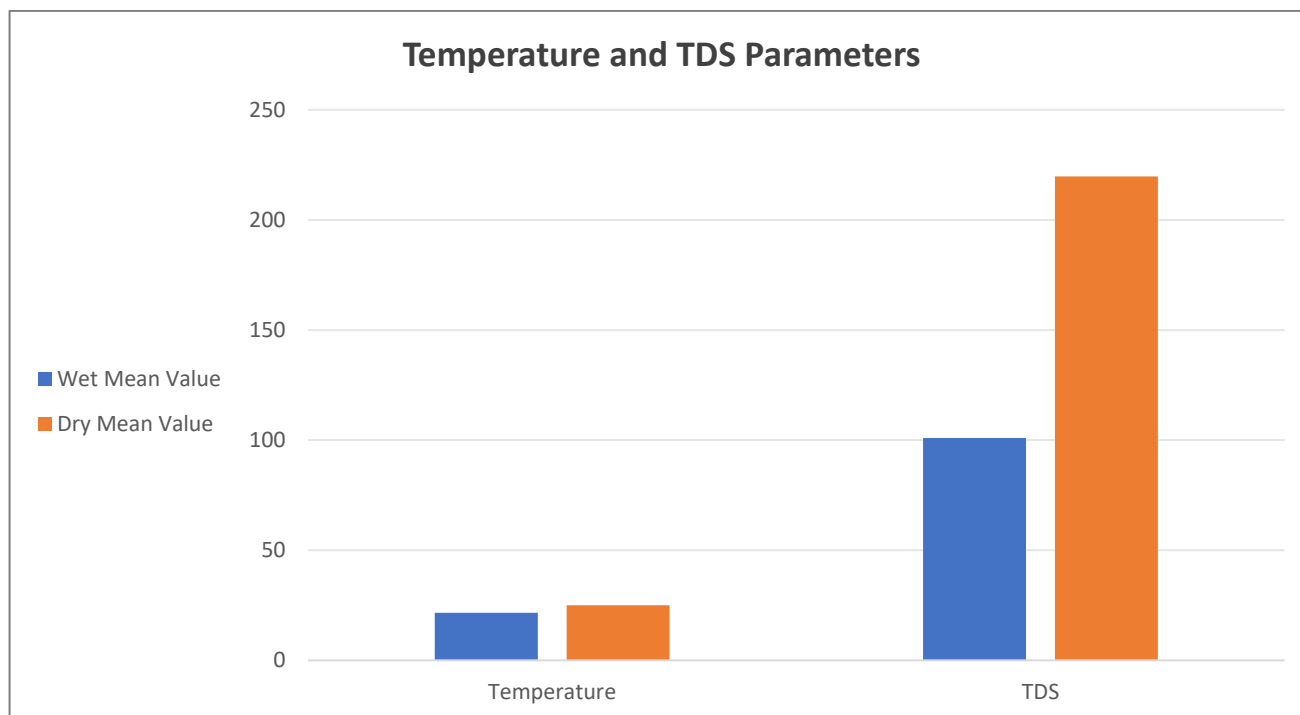
This study enhanced prior findings by reinforcing the special vulnerability of the internally displaced population, which has frequently been ignored in the literature on water quality. The results indicate that the majority of the respondents are youthful females and do not have formal

education, which affects their ability to access, evaluate, and advocate for safe water. The study connects the physicochemical quality of water with social vulnerability and risk perception, providing distinct humanitarian opinions.

**Table 3: Statistical Summary of WQI of the Source of Water at FTC Camp, Maiduguri**

Parameters	Weight (wi)	Relative weight (Wi)	Wet				Dry					
			Ci wet	Si	q wet	SI Wet	Ewi wet	Ci dry	q dry	SI Dry	Ewi dry	
pH	4.0	0.078	6.950	8.50	81.76	6.413	24.386	7.263	85.44	6.701	21.173	
Cl	3.0	0.059	9.000	250.00	3.60	0.212	0.805	14.250	5.70	0.335	1.059	
SO4	4.0	0.078	14.000	100.00	14.00	1.098	4.176	19.750	19.75	1.549	4.894	
NO3	5.0	0.098	0.825	50.00	1.65	0.162	0.615	0.915	1.83	0.179	0.567	
NO2	5.0	0.098	0.006	0.20	2.75	0.270	1.025	0.103	51.25	5.025	15.876	
Mg	2.0	0.039	2.468	50.00	4.94	0.194	0.736	2.360	4.72	0.185	0.585	
Na	2.0	0.039	37.000	200.00	18.50	0.726	2.759	38.750	19.37	0.760	2.401	
Cu	5.0	0.098	0.020	1.00	2.00	0.196	0.746	0.228	22.75	2.230	7.047	
Cr	5.0	0.098	0.006	0.05	11.50	1.128	4.288	0.020	40.00	3.922	12.391	
Mn	5.0	0.098	0.250	0.20	125.00	12.255	46.604	0.123	61.25	6.005	18.973	
Fe	3.0	0.059	0.073	0.30	24.17	1.422	5.406	0.158	52.50	3.088	9.758	
F	3.0	0.059	0.435	1.50	29.00	1.706	6.487	0.318	21.17	1.245	3.934	
Zn	5.0	0.098	0.158	3.00	5.28	0.518	1.968	0.130	4.33	0.425	1.342	
	51.0	1.000	WQI Wet= 26.30					WQI Dry= 31.65				

Source: Field Survey, (2024)



**Figure 1: Inter-Seasonal Variation between Some Parameters**

**Table 4: Summary of HPI**

Metal	Mean Wet Season Concentration (mg/L)	Mean Dry Season Concentration (mg/L)	Average Concentration of Metal (mg/L)	Nigerian Industrial Standard 2007
Chromium (Cr)	0.006	0.020	0.013	0.05
Manganese (Mn)	0.250	0.123	0.187	0.20
Copper (Cu)	0.020	0.228	0.124	1.00
Iron (Fe)	0.073	0.158	0.116	0.30
Zinc (Zn)	0.158	0.130	0.144	3.00

Source: Field Survey, (2024)

**Table 5: ANOVA Result for Chromium**

Source	SS	df	MS	F	p-value
Between Seasons	0.000784	1	0.000784	17	< 0.01
Within Seasons (Error)	0.000267	6	0.0000445		
Total	0.001051	7			

Source: Field Survey (2024)

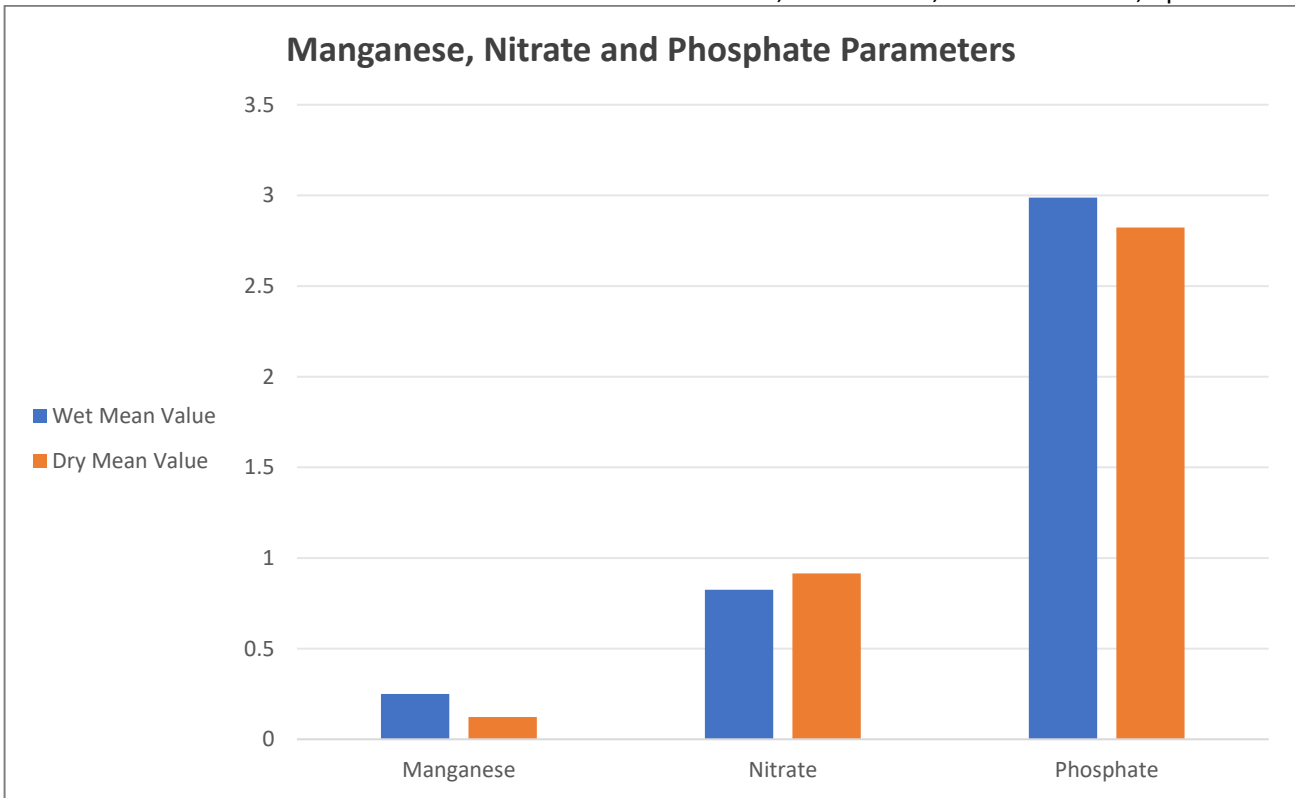


Figure 2: Inter-seasonal Variations between Ionic Parameters

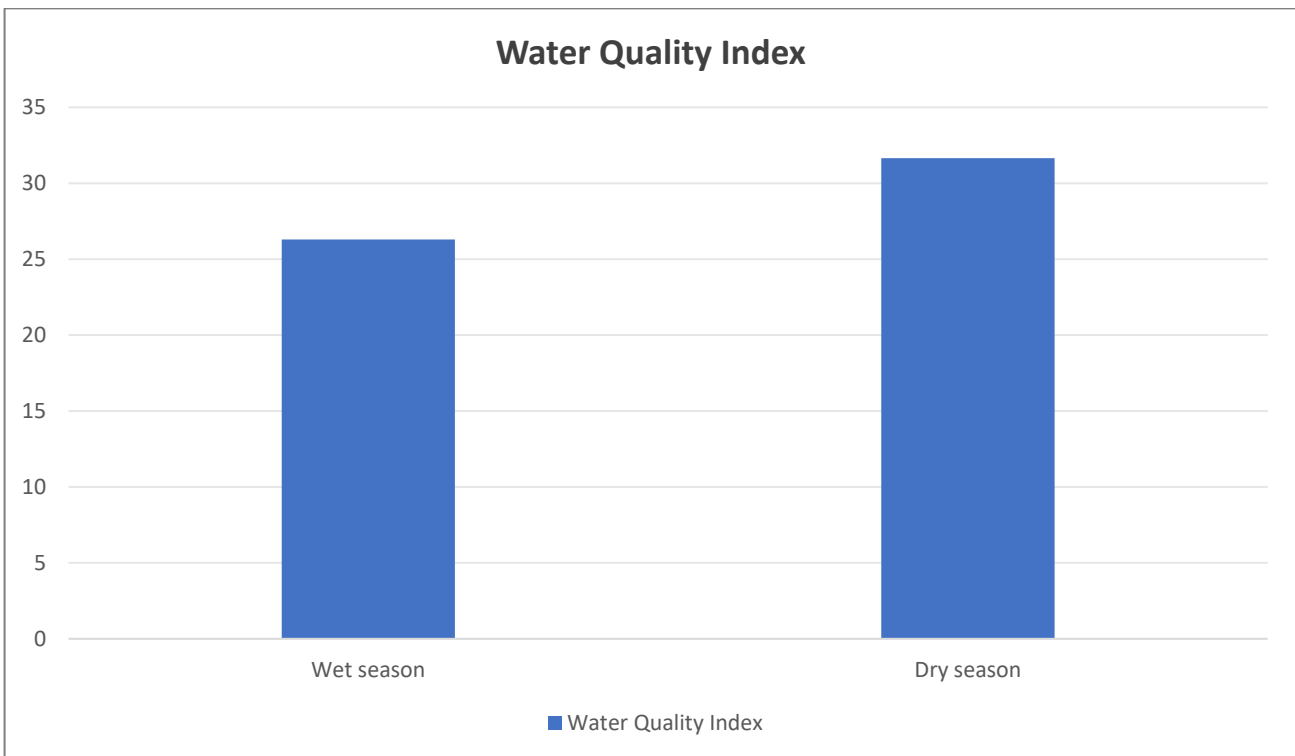


Figure 3: Inter-seasonal Variation between the WQI of Wet and Dry Seasons

### Heavy Metal Pollution Index (HPI) of Water from the FTC IDP Camp Maiduguri

The HPI of 38.04, estimated from Table 4 and obtained from a water sample from the borehole at the IDP camp in FTC Maiduguri, indicates that the water is safe to drink with regard to heavy metals. The HPI result suggests that

the heavy metal pollutants in the water sample are manageable but regular test should be carried out to monitor and preserve members of the community from being casualties as a result of consuming heavy metal polluted water a case which Opasola and Otto (2024) reported in the evaluation of heavy metal levels and contamination indices of groundwater sources in Kaduna South.

**Table 6: Summary of Correlation of Inter-Seasonal Parameters**

	Mean Parameter Wet Season	Mean Parameter Dry Season
Mean Wet Parameter Pearson Correlation	1	0.916**
Sig. (2-tailed)		0
N	15	15
Mean Dry Parameter Pearson Correlation		
Sig. (2-tailed)	0.916**	1
N	0	
	15	15

Source: Field Survey (2024)

### Health Risk Assessment

The health risk assessment carried out on chromium (Cr<sup>3+</sup>) and manganese (Mn<sup>2+</sup>) in the borehole water indicated that the level of exposure of both adults and children to the element is below the exposure level that causes non-carcinogenic health effects. The estimated Hazard Quotient (HQ) of Cr<sup>3+</sup> in the wet and dry seasons was many times lower than the reference dose (RfD), indicating no material threat of chromium ingestion. In all cases, HQ values for Mn<sup>2+</sup> remained below 1, though seasonal peaks occurred, especially during the wet season, when the concentration reached 0.40 mg/L, a level close to that associated with neuro-developmental problems in sensitive groups. Children demonstrated the highest HQ values compared to adults because of their reduced body weight, but their exposure was still within the acceptable range; this finding is consistent with the submission by Preonty et al. (2025). Combined Hazard Index (HI) of Cr<sup>3+</sup> and Mn<sup>2+</sup> was also less than 1, which indicates that the cumulative non-carcinogenic risk in case of these metals is insignificant in the present condition. However, the closeness of the highest level of manganese to the predetermined values of health-based guidelines highlight the necessity of further observation and preventive actions against vulnerable populations in the camp of IDPs (Ogarekpe et al., 2023).

Chromium levels are typically low, indicating a geogenic source. The highest manganese levels occur during the wet season (probably due to leaching from aquifers) and may pose a neurodevelopmental hazard. Although there are minimal risks at the moment, it is important to continue monitoring to safeguard vulnerable camp populations.

### ANOVA and Correlation Results

To determine whether there are significant seasonal changes in nutrient ions, heavy metals, and trace ions in the water samples, an ANOVA test was performed. The outcomes revealed that Cr<sup>3+</sup> showed significant seasonal variation, as shown in Table 5.

The p-value of 0.01 or less suggests a statistically significant difference in chromium concentration between the wet and dry seasons. Its average concentration is higher during the dry season (0.020 mg/l) than during the wet season (0.006 mg/l).

In a similar manner, Table 6 presents the correlation analysis conducted to examine the relationship between 15 wet-season parameters and the dry-season parameter. The result showed that a significant (0.916, p<0.01) relationship between the inter-seasonal parameters.

### Advancement Over Previous Studies

The study builds on the previous research by incorporating physicochemical analysis, WQI computation, and socio-demographic vulnerability profiling among the IDPs (an under-researched population). It also reveals the possibility of HQ, HI, and HPI measurements, which connect the state of the environment to the danger to human health in humanitarian contexts.

### Conclusion and Recommendation

The results indicate that IDPs at FTC camp have socio-economic vulnerabilities as well as water quality problems because the WQI is not suitable for domestic consumption. Though the risks of heavy metals are low, constant surveillance, specific interventions, and enhanced Water, Sanitation and Hygiene (WASH)- related support have to be implemented to ensure the health of the population is preserved.

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