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PHYSICOCHEMICAL AND HEAVY METAL ASSESSMENT OF SHALLOW HAND-DUG WELL WATERS WITHIN MAKURDI TOWN, BENUE STATE, NIGERIA

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ABSTRACT

Water is a ubiquitous chemical substance essential for all forms of life, and access to safe drinking water is critical for public health and well-being. Globally, about 80 % of illnesses are linked to contaminated water and poor sanitation, contributing significantly to mortality rates, particularly in Nigeria and other developing countries. This study assessed the physicochemical properties and heavy metal content of shallow hand-dug well water consumed in Makurdi, Benue State. A total of twenty-five (25) wells were randomly sampled, with five wells selected from each of five locations (Adeke, Gaadi, Kanshio, Wurukum and North Bank). The samples underwent physicochemical and heavy metal analyses to determine compliance with World Health Organization (WHO) and National Agency for Food and Drug Administration and Control (NAFDAC) standards for potable water. Results showed that most physicochemical parameters conformed to WHO (2017) and NAFDAC (2019) standards. However, turbidity exceeded the recommended limit of 5 NTU in Kanshio (6.65±0.45 NTU) and Wurukum (6.24±0.08 NTU). Lead and zinc concentrations were within acceptable limits, while cadmium levels were slightly elevated in Gaadi (0.107±0.005 mg/L), Kanshio (0.086±0.001 mg/L), and Adeke (0.12±0.001 mg/L). Nickel concentrations were also marginally above the permissible limit of 0.02 mg/L across all sampled locations. Overall, most parameters complied with WHO and NAFDAC guidelines, suggesting the water is generally safe for domestic use. However, proactive measures are necessary to control cadmium and nickel levels, as prolonged exposure may pose cumulative health risks.

Keywords: Water; well; physico-chemical; heavy metal; Safety.

INTRODUCTION

Water is one of the most abundant chemical substances in the world. It covers 70 % of the earth surface (Adetoro *et al*., 2020). It is one of the most known compounds to man, water is an essential ingredient of all living organisms and a major component of the environment in which we live (Bank *et al.*, 2018; Yusuf, 2024).

Water pollutants are harmful to the public health and the environment, and they are toxic to the aquatic organisms as well. The water treatment helps to remove contaminants from water to decrease pollutant load (Zhang *et al.*, 2023). Water pollution occurs through natural processes in certain cases, but most of the pollutions caused by human activities (Madhav *et al.*, 2020). Many of these pollutants pose significant risks and problems for both the environment and human health (Ibrahim *et al.*, 2024).

Heavy metals are metals with densities that are five times heavier than water and are formed naturally from the terrestrial environments (Esu *et al.*, 2026). The works of man and his industries have tendencies to increase the quantity of heavy metals in the environment, which favours environmental degradation. But high levels of heavy metals in water can be deleterious and injurious to man's health and his environment (Koller and Saleh, 2018; Orobator *et al.*, 2020; Bibi *et al*., 2023).

In Makurdi, the reliance on shallow hand-dug wells for domestic water supply raises significant concerns regarding water quality and safety. These wells, while essential for daily living, are often vulnerable to contamination from various sources, including runoff from surrounding areas, improper waste disposal, and environmental degradation. The lack of regular monitoring poses serious health risks to the community. (Beyene, *et al.*, 2021; Alsharif, *et al.*, 2023).

MATERIALS AND METHODS

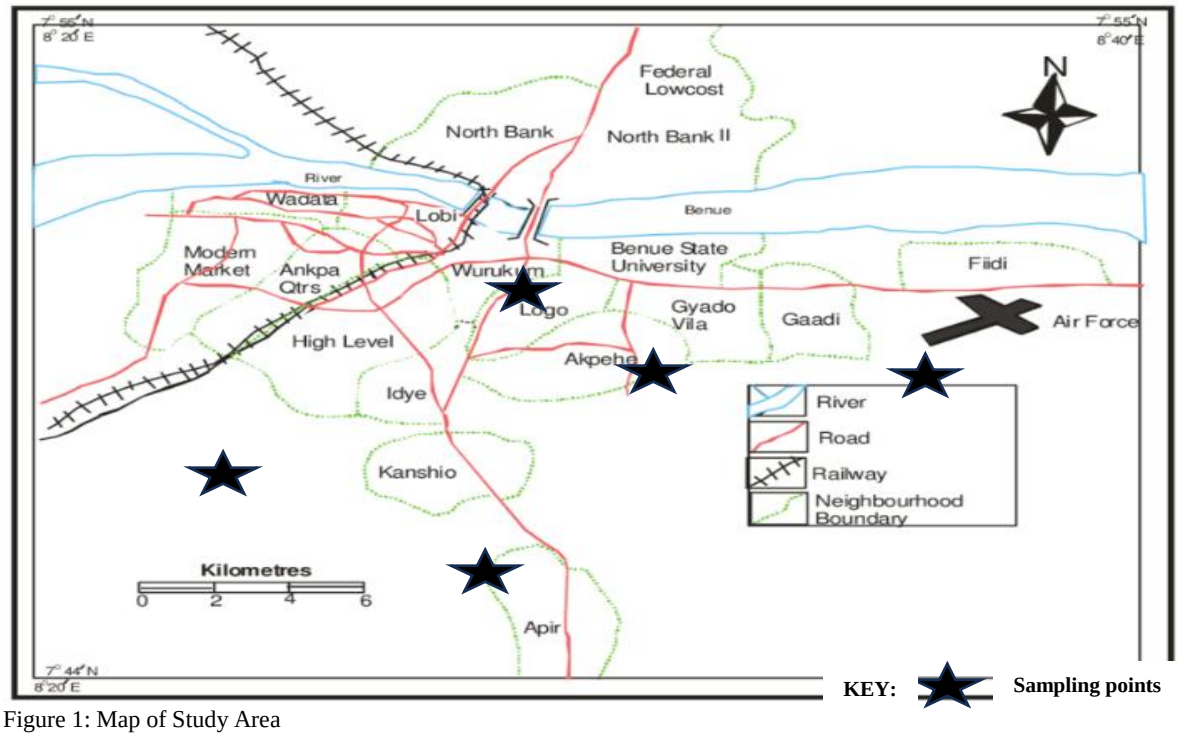

Figure 1: Map of Study Area

Collection of Samples

To ensure adequate representative sampling, a preliminary survey was conducted before selection of locations and wells to be sampled. Five sampling points, with dense population, were adopted which include; Adeke, Gaadi layout, Kanshio, North bank and Wurukum areas. Five (5) samples from five (5) different well waters were identified and collected at each sampling point. The water samples were collected in 1.0 L cleaned and dried plastic containers (washed with detergent and rinsed with distilled water and then dilute nitric acid). During sampling, sample bottles were rinsed with water samples three times and then filled. The samples were collected, then transported to the laboratory, and stored at ambient temperature prior to analysis.

Analysis

Water samples were analyzed for physicochemical parameter such as taste, odour, pH, temperature, electrical conductivity (EC), turbidity, total suspended solid (TSS), total dissolved solid (TDS), total hardness, zinc (Zn), lead (Pb), copper (Cu), cadmium (Cd) and Nickel (Ni).

Taste

A conical flask was rinsed both internally and externally with 4 M HCl solution. It was them rinsed finally with distilled water. The sample was poured into a beaker and the taste determination was done by pouring the water into the mouth so as to detect the taste using tongue by the panel of judges.

Oduor

A conical flask was rinsed both internally and externally with 4 M HCl solution until it was completely odourless. It was them rinsed finally with distilled water and half filled with the sample. The conical flask was stopped and shaken for 3 to 5 seconds. The stopper was removed and the odour noted by closely inhaling the water by the panel of judges.

pH

HANNA pH meter (HI 98107, USA) was used. The meter was calibrated using the buffer solution of 7.0 and 4.0. The steady value of pH read. Reading were in triplicates and average values were recorded.

Temperature

The water was taken in different beaker and the thermometer was dipped in the first beaker for 2 min and the temperature readings were noted in record file.

Electrical Conductivity (EC)

The electrical conductivity of water samples was measured with a TDS meter (Portable E-1, China). 100 mL of water sample was measured and transferred into a beaker and placed on the magnetic stirrer. The electrode which was rinsed with distilled water and carefully wiped with a tissue paper was dipped into the water samples and measurement made after 1 min of stabilizing. The EC of the samples were measured and reported in µS/cm.

Total Suspended Solid (TSS)

TSS was determined using Abbe refractometer at 32 ºC after which temperature correction was made to obtain the corrective total suspended solids of the water sample.

A little amount of the water sample was dropped on the glass slide of the refractometer, which was connected to a light source. The temperature adjuster was used to adjust the temperature and the refractometer was viewed through the monitoring glass space to the scale reading, which gave the total suspended solids of the water sample. The TSS were calculated using a correctional table.

Total Dissolved Solids (TDS)

TDS were determined with a hydrometer. The probe was rinsed with distilled water followed by the water sample to be tested. The raised probe was allowed to sterilized in the

sample for 1 min after which hydrometer values was read directly in Mg/L. The test was performed twice on all samples and values were recorded.

Turbidity

Turbidity of water samples were analyzed using a turbidimeter (HACH 2100P, Germany). The meter was calibrated by standardizing with formazine solution and the water sample was taken in test and placed in turbidimeter. The read key was then pressed and the value of turbidity read directly in NTU. The test was performed thrice on each sample and average values were recorded.

Total Hardness (Microscale Spectrometric Method)

Exactly 5 mL of sample was measured into sample bottles, 5 mL of EDTA, 3 mL of buffer 7.0 and 1mL of calamites was added to the sample respectively. The inoculum was taken to the microscale spectrometer and readings were displayed on the screen and recorded.

Digestion of Water Sample for Metal Analysis

Exactly 100 mL of the water sample was measured into a 250 mL conical flask and 5 mL nitric acid was added. The mixture was heated gently on a hot plate in a fume hood. The sample was heated and reduced to one third of its original volume and the production of clear fumes adjusted that digestion is completed. The sample was allowed to cool down to room temperature and was filtered into 25 mL volumetric flask. The sample made to mark of the volumetric flask with deionized water.

The concentration in mg/L of metals in the digested samples were determined (nitric acid digestion) by means of an Atomic Absorption Spectrophotometer. Specific metal standards in the linear range of the metal were used to calibrate the equipment. The digested samples aspirated and the actual concentrations were obtained by referring to the calibration graph and necessary calculations.

Statistical Analysis

All analyses were carried out in triplicate; data were analyzed using SPSS and presented as mean±standard deviation.

RESULTS AND DISCUSSION

Results of physicochemical parameters of Adeke, Gaadi layout, Kanshio, Wurukum and North bank areas are presented in Table 1,2,3,4 and 5 respectively while the heavy metal results of the respective areas are presented in Table 6, 7, 8, 9 and 10.

Table 1: Result of Physicochemical Parameters at Adeke Area

Parameters	Units	A	B	C	D	E	WHO	NAFDAC
Taste	-	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj
Odour	-	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj
pH	-	6.05^{b}±0.12	5.94^{b}±0.01	6.01^{b}±0.11	6.56^{c}±0.074	5.79^{a}±0.02	6.5-8.5	6.5-8.5
Temperature	ºC	30.17^{a}±0.29	30.1^{a}±0.00	30.1^{a}±0.058	30.3^{a}±0.52	30.03^{a}±0.06	Ambient	Ambient
Conductivity	µS/cm	31.2^{c}±3.13	16.3^{a}±0.30	15.03^{a}±3.58	21.03^{b}±3.13	21.9^{b}±3.86	100-500	1000
TSS	mg/mL	1.66^{ab}±0.23	1.52^{ab}±0.12	1.56^{ab}±0.06	1.32^{a}±0.06	1.66^{ab}±0.058	250	500
TDS	mg/mL	0.014^{a}±0.004	0.012^{a}±0.004	0.039^{a}±0.05	0.015^{a}±0.004	0.0092^{a}±0.004	1000	1000
Turbidity	NTU	1.38^{b}±0.31	1.72^{b}±0.12	1.62^{b}±0.05	1.91^{b}±0.14	2.52b±0.30	5 NTU	5 NTU
Hardness	mg/mL	0.053^{c}±0.003	0.08^{d}±0.02	0.04^{bc}±0.003	0.032^{b}±0.002	0.015^{a}±0.002	<500	60-180

Results are mean±SD of triplicate analysis. Values within the same raw with the same superscript are not significantly different at p>0.05.

Unobj.: Unobjectionable

KEY:

WHO = World Health Organization

NAFDAC = National Agency for Food and Drugs Administration and Control

Table 2: Result of Physicochemical Parameters at Gaadi Layout Area

Parameters	Units	A	B	C	D	E	WHO	NAFDAC
Taste	-	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj
Odour	-	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj
pH	-	6.86^{b}±0.11	6.38^{a}±0.08	7.23^{c}±0.07	6.88^{b}±0.14	6.78^{b}±0.06	6.5-8.5	6.5-8.5
Temperature	ºC	32.7^{a}±1.15	34.0^{b}±1.73	31.6^{a}±0.58	34.0^{b}±1.00	33.3^{a}±1.53	Ambient	Ambient
Conductivity	µS/cm	20.8^{b}±0.92	40.1^{c}±1.098	21.2^{b}±0.20	39.4^{c}±0.55	14.6^{a}±0.21	100-500	1000
TSS	mg/mL	1.49^{a}±0.26	1.45^{a}±0.29	1.35^{a}±0.06	1.72^{a}±0.06	1.49^{a}±0.26	250	500
TDS	mg/mL	0.01^{a}±0.004	0.019^{b}±0.008	0.016^{b}±0.004	0.015^{b}±0.009	0.003^{a}±0.003	1000	1000
Turbidity	NTU	4.35^{c}±0.11	4.31^{c} ±0.11	4.04^{a}±0.082	4.61^{d}±0.093	4.18^{b} ±0.19	5 NTU	5 NTU
Hardness	mg/mL	0.05±0.02	0.04±0.01	0.05±0.01	0.04±0.01	0.03±0.01	<500	60-180

Results are mean±SD of triplicate analysis. Values within the same raw with the same superscript are not significantly different at p>0.05

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Table 3: Result of Physicochemical Parameters at Kanshio Area

Parameters	Units	A	B	C	D	E	WHO	NAFDAC
Taste	-	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj
Odour	-	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj
pH	-	6.59^{a}±0.36	6.88^{ab}±0.106	6.37^{ab}±0.04	6.99^{c}±0.03	6.97^{ac}±0.08	6.5-8.5	6.5-8.5
Temperature	^{o}C	29.1^{b}±0.12	29.1^{b}±0.116	33.1^{c}±0.12	27.0^{a}±0.00	30.0^{d}±0.00	Ambient	Ambient
Conductivity	µS/cm	4.33^{a}±0.06	4.45^{a}±0.06	2.21^{a}±0.01	6.79^{a}±0.006	2.14^{a}±0.37	100-500	1000
TSS	mg/mL	0.37^{a}±0.23	0.333^{a}±0.208	0.17^{a}±0.12	0.50^{a}±0.00	0.23^{a}±0.23	250	500
TDS	mg/mL	0.004^{a}±0.0004	0.0003^{a}±0.00	0.0002^{a}±0.00	0.0006^{a}±0.0002	0.0007^{b}±0.0002	1000	1000
Turbidity	NTU	4.22^{d}±0.16	2.41^{a}±0.16	6.65^{c}±0.45	3.17^{e}±0.12	3.46^{b}±0.14	5 NTU	5 NTU
Hardness	mg/mL	0.031^{a}±0.0007	0.124^{a}±0.16	0.09^{a}±0.012	0.128^{a}±0.17	0.020±0.00	<500	60-180

Results are mean±SD of triplicate analysis. Values within the same raw with the same superscript are not significantly different at p>0.05.
Unobj.: Unobjectionable
KEY:
WHO = World Health Organization
NAFDAC = National Agency for Food and Drugs Administration and Control

Table 4: Result of Physicochemical Parameters of Northbank Area

Parameters	Units	A	B	C	D	E	WHO	NAFDAC
Taste	-	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj
Odour	-	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj
pH	-	7.32^{b}±0.30	6.96^{b}±0.22	7.10^{b}±0.02	7.10^{b}±0.14	6.39^{a}±0.37	6.5-8.5	6.5-8.5
Temperature	^{o}C	27.67a±0.58	27.7^{a}±0.56	30.00^{c}±0.00	29.0^{b}±0.00	30.0^{c}±0.00	Ambient	Ambient
Conductivity	µS/cm	42.9^{a}±0.55	42.8^{a}±0.82	47.23^{b}±0.32	50.4^{c}±1.06	42.8^{a}±0.68	100-500	1000
TSS	mg/mL	1.62^{a}±0.29	1.69^{ab}±0.00	1.62^{a}±0.51	1.69^{ab}±0.00	2.18^{c}±0.02	250	500
TDS	mg/mL	0.00^{ab}±0.00	0.00^{a}±0.00	0.00^{c}±0.00	0.00^{c}±0.00	0.00^{ab}±0.00	1000	1000
Turbidity	NTU	1.84^{a}±0.02	2.03^{a}±0.14	3.38^{c}±0.06	8.28^{b}±0.72	3.16^{b}±0.13	5 NTU	5 NTU
Hardness	mg/mL	0.00^{a}±0.00	0.02^{a}±0.02	0.03^{a}±0.00	0.13^{a}±0.17	0.03^{a}±0.00	<500	60-180

Results are mean±SD of triplicate analysis. Values within the same raw with the same superscript are not significantly different at p>0.05.
Unobj.: Unobjectionable
KEY:
WHO = World Health Organization
NAFDAC = National Agency for Food and Drugs Administration and Control

Table 5: Result of Physicochemical Parameters of Wurukum

Parameters	Units	A	B	C	D	E	WHO	NAFDAC
Taste	-	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj
Odour	-	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj	Unobj
pH	-	7.06^{a}±0.19	7.15^{a}±0.03	7.08^{a}±0.02	7.80^{b}±0.12	7.34^{a}±0.23	6.5-8.5	6.5-8.5
Temperature	^{o}C	28.67^{b}±0.57	28.0^{a}±0.00	30.0^{b}±0.00	28.0^{b}±0.00	28.3^{a}±0.57	ambient	Ambient
Conductivity	µS/cm	71.33^{b}±4.93	83.0^{c}±10.44	90.9^{d}±76.56	81.3^{b}±3.78	33.0^{a}±8.18	100-500	1000
TSS	mg/mL	0.00^{a}±0.00	0.00^{a}±0.00	0.00^{a}±0.00	0.00^{a}±0.00	0.00^{a}±0.00	250	500
TDS	mg/mL	0.50^{a}±0.00	1.00^{b}±0.00	1.00^{b}±0.00	0.50^{a}±0.00	0.80^{b}±0.25	1000	1000
Turbidity	NTU	2.86^{c}±0.130	6.24^{d}±0.08	1.18^{a}±0.06	2.26^{b}±0.09	2.11^{b}±0.16	5 NTU	5 NTU
Hardness	mg/mL	0.00^{a}±0.00	0.00^{a}±0.37	0.00^{a}±0.00	0.00^{a}±0.00	0.00^{a}±0.00	<500	60-180

Results are mean±SD of triplicate analysis. Values within the same raw with the same superscript are not significantly different at p>0.05.
Unobj.: Unobjectionable
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Table 6: Result of Heavy Metal Analysis at Adeke Area (mg/L)

Sample	Zn	Pb	Cu	Cd	Ni
A	0.305^{d}±0.0012	ND	0.100^{b}±0.0027	0.105^{c}±0.0018	0.033^{a}±0.0016
B	0.248^{c}±0.0030	ND	0.074^{a}±0.0009	0.094^{b}±0.0021	0.082^{c}±0.0006
C	0.248^{c}±0.0014	ND	0.072^{a}±0.0015	0.120^{d}±0.0013	0.085^{c}±0.0010
D	0.208^{a}±0.0013	ND	0.101^{b}±0.0015	0.095^{b}±0.0010	0.076^{b}±0.0017

Sample	Zn	Pb	Cu	Cd	Ni
E	0.232^{b}±0.0023	ND	0.120^{c}±0.0015	0.086^{a}±0.0002	0.079^{b}±0.0043
WHO	5	0.01	2	0.003	0.02

Values within the same column with the same superscript are not significantly different at p>0.05.
ND: Non detectable
KEY:
WHO = World Health Organization

Table 7: Result of Heavy Metal Analysis at Gaadi layout Area (mg/L)

Sample	Zn	Pb	Cu	Cd	Ni
A	0.3170^{a}±0.0029	ND	ND	0.0340^{a}±0.0017	0.0080^{a}±0.0013
B	0.4060^{b}±0.0007	ND	ND	0.0500^{a}±0.0010	0.0680^{b}±0.0003
C	0.3880^{b}±0.0022	ND	ND	0.0500^{a}±0.0031	0.1120^{c}±0.0006
D	0.3260^{a}±0.0002	ND	ND	0.1070^{b}±0.0050	0.1030^{c}±0.0012
E	0.3380^{a}±0.0007	ND	ND	0.0060^{a}±0.0006	0.0880^{b}±0.0001
WHO	5	0.01	2	0.003	0.02

Values within the same column with the same superscript are not significantly different at p>0.05.
ND: Non detectable
KEY:
WHO = World Health Organization

Table 8: Result of Heavy Metal Analysis at Kanshio Area (mg/L)

Sample	Zn	Pb	Cu	Cd	Ni
A	0.2960^{a}±0.0002	ND	ND	0.0320^{a}±0.0007	0.0560^{a}±0.0014
B	0.4160^{b}±0.0021	ND	ND	0.0700^{b}±0.0026	0.0750^{a}±0.0075
C	0.3410^{a}±0.0001	ND	ND	0.0580^{b}±0.0016	0.0830^{ab}±0.0011
D	0.4960^{c}±0.0017	ND	ND	0.0860^{c}±0.0012	0.0940^{c}±0.0035
E	0.3440^{a}±0.0001	ND	ND	0.0560^{b}±0.0002	0.0570^{a}±0.0009
WHO	5	0.01	2	0.003	0.02

Values within the same column with the same superscript are not significantly different at p>0.05.
ND: Non detectable
KEY:
WHO = World Health Organization

Table 9: Result of Heavy Metal Analysis at North bank (mg/L)

Sample	Zn	Pb	Cu	Cd	Ni
A	0.4230^{c}±0.0012	ND	ND	0.0013^{b}±0.0020	0.0705^{d}±0.0005
B	0.3820^{b}±0.0031	ND	ND	0.0004^{a}±0.0004	0.0428^{c}±0.0028
C	0.5470^{d}±0.0004	ND	ND	0.0018^{b}±0.0018	0.0216^{b}±0.0012
D	0.2650^{a}±0.0032	ND	ND	0.0017^{b}±0.0018	0.0212^{b}±0.0015
E	0.3080^{a}±0.0017	ND	ND	0.0018^{b}±0.0013	0.0315^{b}±0.0016
WHO	5	0.01	2	0.003	0.02

Values within the same column with the same superscript are not significantly different at p>0.05.
ND: Non detectable
KEY:
WHO = World Health Organization

Table 10: Result of Heavy Metal Analysis at Wurukum Area (mg/L)

Sample	Zn	Pb	Cu	Cd	Ni
A	0.3920^{c}±0.0011	ND	ND	0.0032^{b}±0.0014	0.0890^{a}±0.0013
B	0.3330^{b}±0.0017	ND	ND	0.0025^{b}±0.0002	0.0940^{a}±0.0017
C	0.3600^{b}±0.0022	ND	ND	0.0010^{a}±0.0004	0.1525^{b}±0.0040
D	0.3440^{b}±0.0017	ND	ND	0.0014^{a}±0.0001	0.1071^{b}±0.0071
E	0.3020^{a}±0.0016	ND	ND	0.0006^{a}±0.0004	0.1420^{b}±0.0023
WHO	5	0.01	2	0.003	0.02

Values within the same column with the same superscript are not significantly different at p>0.05.
ND: Non detectable
KEY:
WHO = World Health Organization

Discussion

Physicochemical Parameters

Across all study areas (Adeke, Gaadi, Kanshio, Northbank, and Wurukum), the water samples were reported as unobjectionable in taste and odour, which aligns with the WHO (2017) and NAFDAC (2019) standards that recommend potable water to be free from offensive taste and odour. The absence of undesirable sensory characteristics suggests minimal organic contamination and supports the aesthetic quality of the sampled water (Ojo *et al.*, 2021).

The pH values ranged from 5.78±0.02 to 7.80±0.12, indicating that most samples were within the WHO/NAFDAC permissible limits (6.5–8.5) except for slightly acidic values observed in Adeke (5.78±0.02–6.56±0.07). Slight acidity may result from geological formations, organic decay, or industrial emissions (Owamah & Izinyon, 2015b). Conversely, samples from Wurukum (7.06±0.19–7.80±0.12) and Northbank (6.39±0.37–7.32±0.30) were near neutral to slightly alkaline, typical of groundwater interacting with carbonate-rich formations (Adetunde et al., 2020). Maintaining neutral pH is vital since acidic water can corrode pipes, while alkaline water may affect disinfection efficiency.

Water temperature ranged between 27.0±0.00°C and 34.0±1.73°C across all sites, consistent with ambient tropical conditions. The WHO (2017) does not specify a strict limit but recommends temperatures close to ambient to maintain palatability and prevent microbial proliferation. The slightly elevated temperatures in Gaadi (up to 34°C) may enhance microbial growth potential (Obeta & Nwosu, 2020a).

Conductivity values varied significantly among the sites: Adeke: 15.03±3.58–31.23±3.12 µS/cm, Gaadi: 14.6±0.21–40.1±1.10 µS/cm, Kanshio: 2.14±0.37–6.79±0.01 µS/cm, Northbank: 42.8±0.82–50.4±1.06 µS/cm and Wurukum: 33.0±8.18–90.96±76.6 µS/cm. All were below WHO (100–500 µS/cm) limits, indicating low ionic concentration and minimal dissolved mineral content. Such low EC values are typical of soft water, though very low readings, such as in Kanshio, may indicate limited buffering capacity and susceptibility to pH fluctuations (Okoye *et al.*, 2022).

TSS values were low across all sites, ranging from 0.00±0.00–1.72±0.06 mg/mL, far below the WHO limit (250 mg/L), suggesting effective natural filtration or minimal surface runoff contamination.

TDS ranged from 0.00±0.00–1.00±0.00 mg/mL, also significantly lower than the 1000 mg/L permissible limit, reflecting good aesthetic and chemical quality. According to Edokpayi *et al.* (2018a), low TDS indicates limited salinity and non-mineralized groundwater sources, making the water suitable for domestic use.

Turbidity values were within acceptable limits (≤5 NTU) for most samples, except for slightly elevated readings in Northbank (8.28±0.72 NTU) and Gaadi (4.61±0.09 NTU). Turbidity exceeding 5 NTU may hinder disinfection efficiency and indicate suspended particulates or microbial presence (WHO, 2017). High values in Northbank could stem from anthropogenic inputs such as runoff and waste discharge, as noted by Ishaya *et al.* (2022a) in similar urban environments.

Hardness values were generally very low (0.00±0.00–0.13±0.17 mg/mL) across all locations, below the WHO maximum of 500 mg/L. This suggests the water is soft, likely due to low calcium and magnesium concentrations. While soft water is desirable for domestic use, extremely low hardness can increase the risk of corrosion in plumbing systems (Srinivasan & Reddy, 2019b).

Heavy Metal Concentrations

Zinc concentrations across all study areas ranged from 0.208±0.00–0.547±0.00 mg/L, with the highest recorded in Northbank (0.547±0.00 mg/L) and the lowest in Adeke (0.208±0.00 mg/L). These values are well below the WHO (2017) guideline limit of 5.0 mg/L, indicating that zinc contamination in the water samples is minimal. Zinc is an essential trace element required for biological functions but can cause undesirable taste and gastrointestinal distress at concentrations above the permissible limit (Adeniyi & Ipinmoroti, 2019). The observed concentrations suggest no immediate health concern and reflect natural geogenic origins, possibly from weathering of zinc-bearing minerals or galvanized pipes (Edokpayi *et al.*, 2018b).

Lead was non-detectable (ND) in all samples across Adeke, Gaadi, Kanshio, Northbank, and Wurukum. This is a positive indicator since WHO (2017) recommends that lead should not exceed 0.01 mg/L in drinking water due to its severe toxicity, especially in children. The absence of detectable lead may indicate minimal anthropogenic pollution such as from old plumbing or industrial effluents. Lead-free results have also been reported in groundwater studies in Makurdi and other parts of North Central Nigeria (Ishaya *et al.*, 2022b; Obeta & Nwosu, 2020b), supporting the observation of low lead exposure in this area.

Copper was detected only in Adeke (0.072±0.00–0.120±0.00 mg/L), while it was non-detectable (ND) in the other four locations. These values are far below the WHO limit of 2.0 mg/L, indicating safe levels for human consumption. Trace amounts of copper are essential for metabolic processes but can cause astringent taste and health issues at high concentrations (Owamah & Izinyon, 2015a). The moderate values in Adeke may originate from corrosion of copper plumbing or leaching from soil minerals (Srinivasan & Reddy, 2019a).

Cadmium concentrations varied among sites, with Adeke (0.086±0.00–0.120±0.00 mg/L) showing the highest levels, while other locations (Gaadi, Kanshio, Northbank, and Wurukum) recorded lower concentrations (0.0004±0.00–0.107±0.01 mg/L). Notably, all the values exceeded the WHO permissible limit of 0.003 mg/L, indicating potential contamination concerns. Elevated Cd levels may stem from agricultural activities, improper waste disposal, or battery and metal plating wastes in the area (Adelekan & Abegunde, 2011). Chronic exposure to cadmium can result in kidney dysfunction and skeletal damage (WHO, 2017). Hence, the detected Cd concentrations, particularly in Adeke and Gaadi, pose a potential health risk if the water is consumed untreated.

Nickel concentrations ranged from 0.008±0.00 to 0.1525±0.00 mg/L, with the highest observed in Wurukum (0.1525±0.00 mg/L) and the lowest in Gaadi (0.008±0.00 mg/L). Most values exceeded the WHO limit of 0.02 mg/L, suggesting possible anthropogenic influence. Elevated Ni concentrations may originate from industrial runoff, metal corrosion, or geological sources such as ultramafic rocks (Okoye et al., 2022). Prolonged exposure to nickel-contaminated water is associated with dermatitis, respiratory disorders, and carcinogenic effects (USEPA, 2018). The relatively higher Ni in Wurukum and Kanshio could indicate urban runoff or industrial discharges, consistent with previous studies in urbanized regions of Benue State (Ishaya *et al*., 2022).

CONCLUSION

All physicochemical parameters were largely within WHO (2017) and NAFDAC (2019) recommended limits, indicating good water quality in the studied areas. Minor deviations—

such as low pH in Adeke and elevated turbidity in Northbank—highlight localized geochemical and anthropogenic influences. Generally, the water quality is suitable for domestic consumption, but periodic monitoring is recommended to detect potential contamination from urban expansion or seasonal variations.

All zinc, copper, and lead concentrations were within WHO limits, reflecting generally low heavy metal contamination and satisfactory water quality for domestic use. However, cadmium and nickel exceeded permissible limits in most samples, raising toxicological concerns. Continuous exposure to Cd and Ni can pose cumulative health risks even at trace levels (Edokpayi *et al.*, 2018). Therefore, regular monitoring and treatment (e.g., adsorption, ion exchange) are recommended before consumption.

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