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Physio-chemical and Microbial Assessment of the Source of Drinking Water and the Prevailing Waterborne Diseases in Gwagwalada Municipal Area Council of Abuja, Nigeria

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Abstract
Water contamination poses a serious threat to the wellbeing of people globally. In Nigeria, there have been increasing cases of waterborne diseases owing to water contamination, thus becoming public health concerns. This study investigated the physio-chemical properties, microbial loads of borehole water samples from Gwagwalada area council of Abuja and its prevailing waterborne diseases. Borehole water samples were collected from five wards of the council area (Gwagwalada central (YZTM), University of Abuja Staff quarters (YZTMB), Dobi (SBWTM), Tunga Maje (TMCBW), and Ikwa (YZBTM) in triplicate and analyzed for physiochemical properties (temperature, conductivity, pH, turbidity, salinity, total dissolved solids (TDS), and heavy metals) and microbial contamination using standard methods. Surveillance to determine the prevalence of waterborne diseases was also carried out in the health facilities of the area council. All samples showed variable concentrations in most of the physio-chemical parameters and were within the recommended thresholds except for conductivity (596.01 ± 0.00 µS/cm) and chlorine (254.18 ± 0.00 mg/l) in TMCBW sample and total dissolved solids in TMCBW (948.01 ± 14.14 mg/l) and YZTM (GC) (1871.00 ± 55.15 mg/l) water samples. E. coli, Enterobacter spp., Shigella spp., Lactobacillus spp., Pseudomonas ssp., and Proteus ssp. were bacteria isolates of the samples. Principal component analysis of interrelationship showed a strong positive relationship between some physio-chemical parameters and sampling locations. Also, there was heavy burden of gastrointestinal (waterborne) diseases. The study concludes that the borehole samples from the area were contaminated and maybe unfit for consumption. Thus, call for interventions that provide safer portable water or treat existing water sources towards achieving SDG No. 6 and to prevent outbreaks of waterborne diseases that could emanate from the consumption of unsafe water.

Keywords: Water contamination, Physio-chemical parameters, Water-borne disease, Sustainable development Goal 6

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INTRODUCTION

Water is an essential requirement for life. The Sustainable Development Goal (SDG) Target No. 6.1 calls for universal and equitable access to safe and affordable drinking water for all by 2030 (WHO, 2019). The target is tracked with the indicator of having "safely managed drinking water services, drinking water from an improved water source that is located on premises, being available when needed, and free from fecal and chemical contamination." According to the World Health Organization (WHO), 5.3 billion people of the 7.9 billion global population used safely managed drinking-water services in 2017 (WHO, 2019). Out of the remaining 2.4 billion people without safely managed drinking-water services in the same year, 579 million people were taking water from unprotected wells and springs and untreated surface water from lakes, ponds, rivers, and streams. This figure shows that half a billion people have challenges accessing safe drinking water, which signifies a failure to achieve Sustainable Development Goal Target 6.1. (SDG 6.1). Waterborne diseases are considered a rapidly growing threat to the health and wellbeing of populations in countries worldwide and have become one of the most serious public health challenges of the 21st century, with the problem reaching a global dimension and steadily affecting many low- and middle-income countries. In Nigeria, there have been increasing cases of waterborne diseases, and this is becoming a public health challenge. Some waterborne diseases commonly found in Nigeria include cholera, typhoid, diarrhea, hepatitis, and dysentery (Yusuff *et al*., 2014). The majority of waterborne diseases are caused by the ingestion of water contaminated by disease pathogens such as bacteria, protozoa, and viruses. Cholera, for example, is a serious endemic waterborne disease in Nigeria, and its re-emergence occurs almost annually in Nigeria, particularly in the northern regions of the country. In 2022, about 10,540 suspected cases of cholera were reported in 32 states of the Federation, including the Federal Capital Territory, and 256 deaths were recorded, representing a case fatality rate (CFR) of 2.3%. (NCDC, 2022). Many communities in Nigeria are limited in the availability of clean and safe drinking water and therefore inadequate to meet the requirements of their large populations. People often resort to other means of obtaining drinking water to meet their needs. Some of the means include rivers, streams, and groundwater such as boreholes, wells, etc. According to Jibrin *et al*. (2015), boreholes are the most commonly consumed underground water in rural Nigeria. These water sources often contain many microbial and chemical impurities resulting from environmental and human activities, and when consumed as drinking water, they expose people to waterborne pathogens, thereby increasing morbidity and mortality from waterborne diseases (Adefemi and Awokunmi, 2010). These water sources often contain many microbial and chemical impurities resulting from environmental and human activities, and when consumed as drinking water, they expose people to waterborne pathogens, thereby increasing morbidity and mortality from waterborne diseases (Adefemi and Awokunmi, 2010). Additionally, chemical contamination of drinking water has also become a serious public health challenge. It has been shown that chronic exposure of drinking water to chemical contaminants or heavy metals such as lead, arsenic, cadmium, etc. can lead to various forms of cancer (e.g., skin, lung, liver, bladder), liver diseases, and diabetes mellitus (Tortora *et al*., 2002). Lead exposure is associated predominantly with cognitive, behavioral, and developmental impacts, which are particularly harmful to young children (Boskabady, 2018). Therefore, the availability of a good-quality water source is paramount for the prevention of waterborne diseases and improving the quality of life (Jibrin, 2019). The present study aimed to investigate the physio-chemical, heavy metal content, and microbial contamination of drinking water in Gwagwalada Municipal Area Council of the Federal Capital Territory, Abuja, and its prevailing waterborne diseases. Examining the conditions of the water available in these communities for drinking will help inform the status of the drinking water and will further guide the appropriate authorities on the necessary policies and measures to be put in place to correct any deficit in the supply of safe drinking water towards actualizing SDG No. 6 (clean water and sanitation).

MATERIALS AND METHODS

Materials
The materials used for this study include: thermometer (JEL-100), pH meter (PHS-3E, Labo Hub), electrical conductivity meter (INE-EC110B, MRC instrument), sterilized petri dishes, lenses, absorbent pads, ice packs, water samples, membrane filtration apparatus, marker, masking tape, Bushen flame, hot plate, forceps, distilled water, incubator, autoclave, filter paper, wire loop, nutrient agar, microscope, weighing balance, desiccators, autoclave, spatula, Durham tubes, and HANNA spectrophotometer (Model 98129, China).

Methods

Study location
Gwagwalada is one of the six (6) Area Councils in the Federal Capital Territory (FCT), Abuja, Nigeria. It has an area of 1,043 km^2 and a population of over 346,000. Gwagwalada is about 57 km from Abuja main city. Gwagwalada Council Area is also the host community for the University of Abuja. The Gwagwalada Area Council of the FCT was selected for this study because it had a population that was fairly representative of the residents in Abuja in terms of varying socioeconomic indices, and the majority of households had different sources of drinking water.

Sampling stations
Five wards in Gwagwalada Area Council were selected by a random sampling method. The wards selected included Gwagwalada Central, University of Abuja Staff Quarters, Dobi, Tunga Maje, and Ikwa.

Collection of water samples
The water samples were collected from each ward's Gwagwalada central, University of Abuja Staff quarters, Dobi, Tunga Maje, and Ikwa major source of drinking water (borehole) into clean, transparent amber bottles by first rinsing the bottles with the water samples and were labelled YZTM, SBWTM, YZTMB, TMCBW and YZBTM respectively. All the water samples were collected by early hours (between 7 a.m. and 9 a.m.) of the day in triplicate. Some physicochemical parameters, which include pH, temperature, total dissolved solids, and electrical conductivity, were determined at the point of collection and were later transferred into ice-pack and 50 ml sterile sample bottles for other physicochemical and heavy metal analysis respectively and transferred later to the laboratory for an immediate analysis. This study was conducted in August, 2022.

Physiochemical Analysis
The water samples were subjected to different physiochemical (temperature, pH, conductivity, and total dissolved solids) and elemental (chlorine, manganese, lead, and cadmium) analyses using the standard methods of APHA (1995) and FAO (1997).

Colour and turbidity
The colour of the water samples was determined using a colour analyzer (WR10QC, China). The turbidity was measured by the use of turbidity meter (BEP-TB100, Infitex); the meter contains a bottle in which the water samples were induced. The bottle was inserted into a

cavity hole on the turbidity meter which was allowed to read for 30 seconds, there after the reading was recorded.

pH Value
The pH was determined using the pH meter (PHS-3E, Labo Hub instrument). Buffer solutions of different pH was used to standardize the pH meter.

Electrical conductivity
Electrical conductivity of the water samples was estimated by the use of a conductivity meter (INE-EC110B, mrc instrument). The conductivity meter was standardized with buffer solution and temperature of different samples before the steady readings were noted.

Temperature
The temperature of each water sample was determined through the use of a mercury-bulb thermometer by immersing the bulb vertically into the samples and allowing it to stand until a steady temperature was achieved.

Total hardness
The hardness of the water samples was determined by employing the EDTA trimetric method of APHA (1995). Fifty (50) ml of the water sample was pipetted into a conical flask, to which 1 ml of ammonium buffer and 3 drops of Eriochrome black T indicator were added. The mixture was titrated against 0.01 M EDTA until a blue color was formed, thus marking the end point.

Total dissolved solids (TDS)
An empty beaker was weighed, and 50 ml of the water sample was measured into it and filtered into another beaker. The filtrate was heated to dryness, cooled, and reweighed until a constant mass was obtained. The value of the mass was recorded using the expression

$$TDS = \frac{W_1 - W_2 \times 1000}{\text{sample volume (ml)}}$$

Dissolved oxygen (DO)
The dissolved oxygen content of the water samples was measured by using a waterproof meter according to standard method of APHA (1995).

Elemental Analysis
A portable handheld HANNA instrument (spectrophotometer) model 98129 was used to digitally determine the concentration of chlorine, manganese, sulfate (SO_4), phosphate (PO_4), and nitrate (NO_3) in the water samples.

Heavy metals
The screening of water samples for potential heavy metals (lead, cadmium, mercury, copper, and chromium) was aided by simple digestion followed by analysis with an atomic absorption spectrophotometer (AAS), Model SP-AA4530, SCITEK, China.

Microbial Analysis

Total bacterial count
The total bacterial count from the borehole water samples was determined using standard methods of APHA (1985) that employ the pour plate technique. A nutrient agar medium was employed to enumerate the bacteria in the samples.

Total coliform count
The total coliform term was determined by employing the MPN index method using the 3-3-3 regimen.

The fecal coliform counts
The fecal coliform count was determined by employing the pour plate technique as described by the method of Burnett and Beuchat (2001). *E. coli* strains appeared as greenish metallic sheen colonies, and this was further confirmed by the ability of the organism to ferment lactose at 44.5°C.

Identification of bacteria isolates
All isolates were identified by using standard methods as described by APHA (1985), Burnett and Beuchat (2001) and Fawole and Oso (2001).

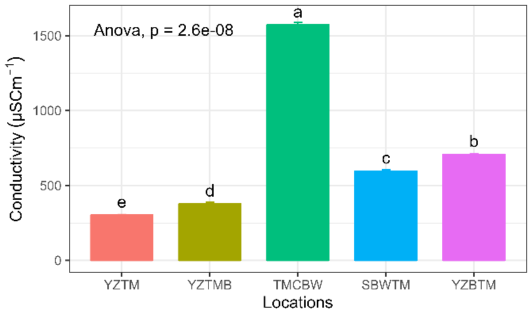
Surveillance hospitals
A surveillance record from the healthcare facilities located in the Gwagwalada Area Council was used as secondary data to determine the prevalence of waterborne disease the Area Council. The health facilities included: i. University Teaching Hospital; ii. Gwagwalada Clinic and Maternity, Kutunku iii. Primary Health Care Center, Chitumu iv. Primary Health Center, Dukpa v. Gwakwo Primary Health Care Centre. The surveillance record captured children and adults between the ages of 2 to 28 years who had visited the health facilities between August 2021 and July 2022 and were diagnosed with waterborne disease.

STATISTICAL ANALYSIS
The data were subjected to a one-way analysis of variance to compare the mean difference in physiochemical parameters, heavy metals and bacteria across the sampling points. Where a significant difference ($p < 0.05$) exists, Tukey's post hoc test was employed to separate the means.

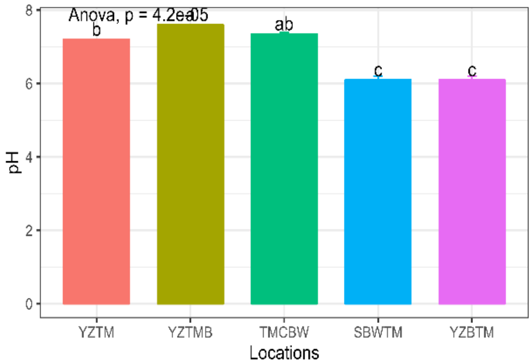
RESULTS
The results of the physicochemical analysis of the borehole water samples are depicted in Table 1 and Figures 1–2, respectively. The results were compared with the World Health Organization (WHO) and Nigerian Guideline Value (NGV) Table 2. The temperature of the borehole water samples from the sampling locations ranged from 26.15 to 26.70^{o}C and was not significantly different among the samples (Table 1). The electrical conductivity significantly ($p < 0.05$) varied among the borehole samples in the order TMCBW > YZBTM > SBWTM > YZTMB > YZTM and was within the NGV acceptable value except for the TMCBW (Tunga Maje) sample (Figure 1a). The pH of the borehole water samples ranged from 6.10 to 7.60; the lowest pH (6.10) was recorded for YZBTM (Ikwa community) and SBWTM (Dobi community) borehole water samples, which were not significantly ($p< 0.05$) different from each other, while borehole water samples from YZTMB (University of Abuja Staff Quarters) recorded the highest pH (7.60). The pH of all the water samples collected was within the permissible thresholds of WHO and NGV (Figure 1b). The total hardness (TH) of the five borehole water samples falls within the recommended WHO and NGV thresholds but varies significantly ($p < 0.05$) among the water samples. The TMCBW water sample had the highest TH (110.00 mg/l), while the lowest TH (60.00 mg/l) was recorded in the SBWTM water sample (Figure 1c). The total dissolved solids (TDS) in YZTM and TMCBW borehole water samples were above the NGV permissible level and were 1871 ± 55.10 mg/l and 948 ± 14.14 mg/l respectively (Figure 1d). The total dissolved solids from YZTMB, SBWTM, and YZBTM were below the NGV permissible level and in the order YZTMB (231 ± 8.48 mg/l) < SBWTM (361.50 ± 7.77 mg/l) < YZBTM (430 ± 5.65 mg/l). In Figure 1e, the YZTM borehole water

sample had the highest color (176.50 ± 2.12 TCU) and turbidity (27.40 ± 0.28 NTU), followed by the SBWTM borehole water sample (Figure 1f) when compared to the other three borehole water samples. The lowest color (0.01 ± 0.01 TCU) and turbidity (1.74 ± 0.18 NTU) were found in the borehole water samples collected from YZBTM. The level of salinity among the samples ranged from 0.40 to 0.90 mg/ml (Figure 1g).

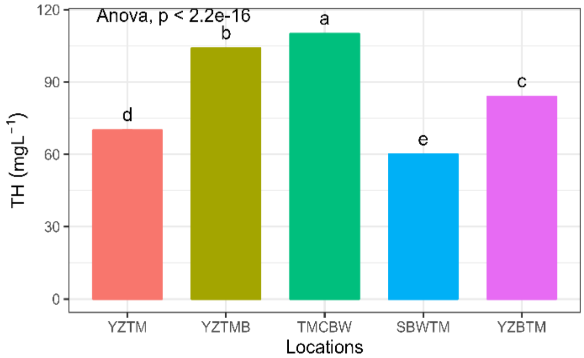
The results of the elemental analysis of the borehole water samples are presented in Table 1 and Figure 2. The chlorine concentrations from YZTM (54 mg/l), YZTMB (14.20 mg/l), SBWTM (55.38 mg/l), and YZBTM (80.94 mg/l) borehole water samples were within the recommended threshold, while the chlorine concentration of the TMCBW (254.18 mg/l) borehole water sample exceeded the recommended threshold by WHO/NGV (Figure 2a). There was no traceable amount of iron in YZTMB, SBWTM, TMCBW, and YZBTM borehole water samples except for the YZTM sample (Figure 2b). Also, there were no traceable amounts of phosphate, nitrate, sulfate, zinc, manganese, lead, or cadmium in the SBWTM and YZBTM samples. However, the traceable amounts of iron, phosphate, nitrate, sulfate, zinc, manganese, lead, cadmium, and copper (Figures 2c–2j and Table 1 respectively) in borehole samples of YZTM, YZTMB, and TMCBW were below the permissible levels. The plot in Figure 3a depicts the correlation between the physiochemical parameters investigated. The physiochemical parameters with significant positive correlations were grouped together and indicated in the square box with positive values of 0.5–1 (i.e., 0.5, 0.6, 0.7, 0.8, 0.9, and 1), as seen in Figure 3a. The physiochemical parameters with a significant negative correlation are grouped together and are indicated in the square box with negative values of -0.5 to -1 (i.e., -0.5, -0.6, -0.7, -0.8, -0.9, and -1) while those with a non-significant correlation are grouped together and marked by X in the square box, as seen in Figure 3a. The principal component analysis (PCA) of the inter-relationship between the physiochemical parameters and sampling locations is presented in Figure 3b, while Figure 3c depicts the cluster dendrogram showing the similarity between sampling locations relative to the physicochemical parameters. In Figure 3b, the first component (Y-axis: Dim2 = 33.2%) and second component (X-axis: Dim2 = 51.3%) accounted for 84.6% of the entire variation in the dataset. A strong positive relationship existed between EC, Cl, Sal, TH, and the sampling location of TMCBW. Also, turbidity, Fe, Mn, PO4, NO3, and color showed a positive relationship with the sampling location, YZTM. Temperature had a negative relationship with most of the parameters determined in this study. Temperature was observed to be higher for SBWTM and YZBTM. In the cluster dendrogram, it was observed that SBWTM, YZBTM, and YZTMB had similar physiochemical and heavy metal properties compared to the other locations at a similarity level of 5. YZTM and TMCBW had distinct physicochemical characteristics; hence, they did not form a cluster at 6.0 (Figure 3c). Table 3 shows all the biochemical characteristics of the isolates identified in borehole water samples. Six genera of bacteria were isolated from the water samples. The bacteria isolated include *Proteus spp., Enterobacter spp., Pseudomonas spp., Escherichia coli., Lactobacillus, and Shigella. E. coli* strains appeared as greenish metallic sheen colonies on the nutrient agar. The total bacteria count of the borehole water samples ranged from zero to 120 cfu/ml. The YZBTM recorded the lowest (32 cfu/ml), while the highest bacteria count (120 cfu/ml) was recorded in the YZTM water sample. The total coliform count ranged from zero to 23 MPN index of coliform/100 ml, with the water sample from YZBTM exhibiting the lowest (MPN 7 cfu/100 ml) coliform count while the water sample from YZTM and SBWTM exhibiting the highest (MPN 23 cfu/100 ml) coliform count (Table 3). The fecal count ranged from zero to 80 cfu/ml, with the highest (80 cfu/ml) recorded in both YZTM and YZBTM borehole water samples and the lowest (35 cfu/ml) recorded in the SBWTM water sample. The borehole water sample from TMCBW was devoid of bacterial, coliform, and fecal counts, i.e., zero counts. Hospital surveillance on the number of cases of waterborne disease recorded at the five health facilities visited in Gwagwalada Area Council for a period of one year (August 2021–July 2022) is presented in Table 6. A total of 218 cases of waterborne diseases were recorded across the five health facilities among different age groups. The highest number of cases of waterborne disease were recorded in children < 5 years from all the health facilities, with the University of Abuja Teaching Hospital topping the list (Table 6).



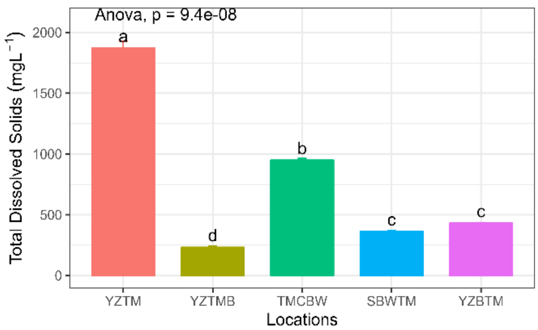
1a: Electrical conductivity of borehole water samples



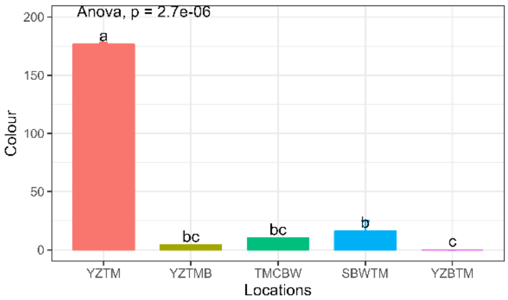
1b: pH of borehole water samples



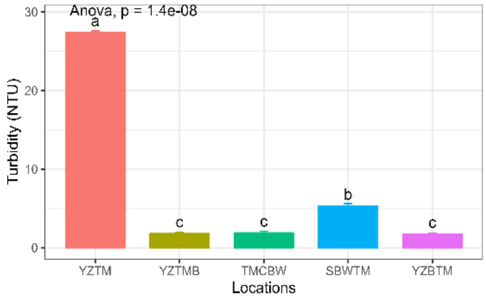
1c: Total hardness of borehole water samples



1d: Total dissolved solids of borehole water samples



1e: Colour of borehole water samples



1f: Turbidity of borehole water samples

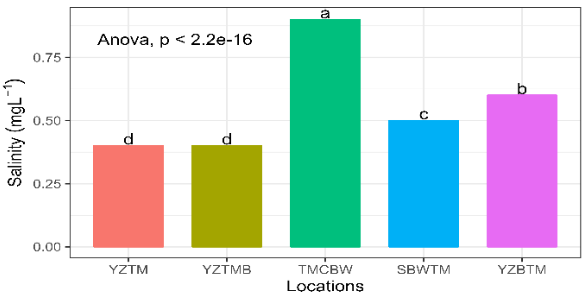


Figure 1g: Salinity of borehole water samples

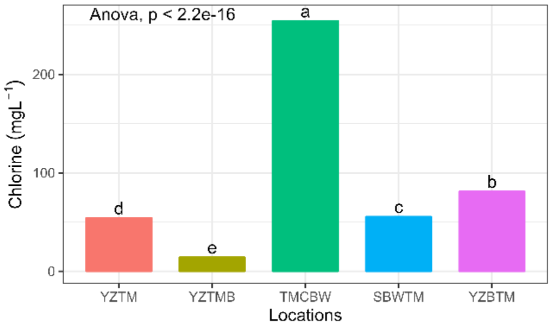
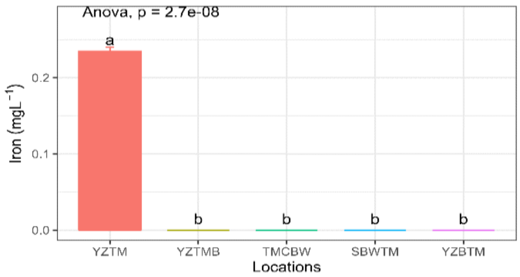
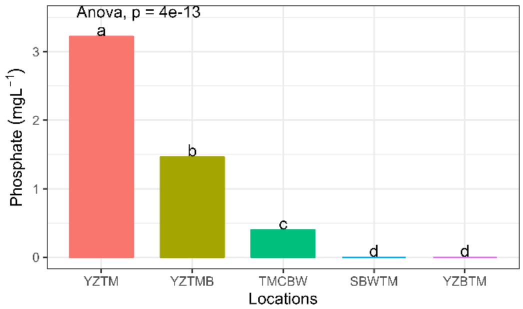


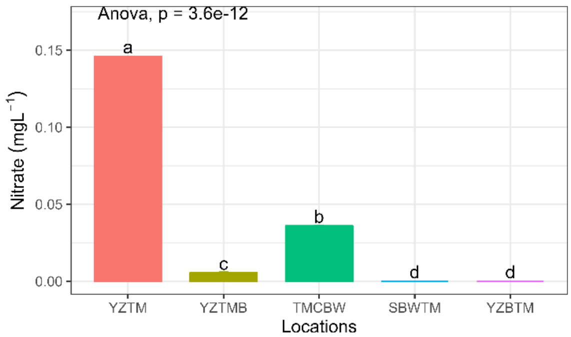
Figure 2a: Chlorine content of borehole water samples



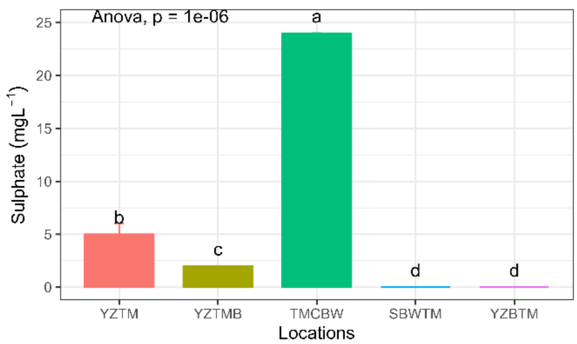
2b: Iron content of borehole water samples



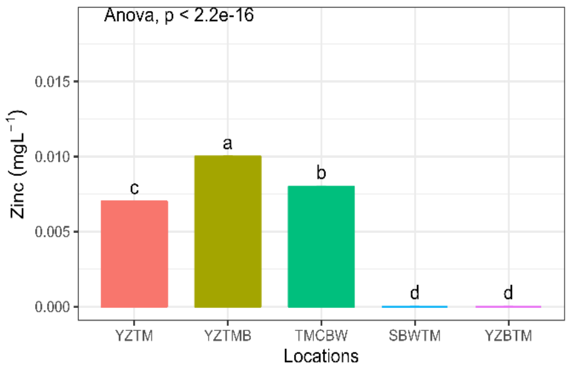
2c: Phosphate content of borehole water samples



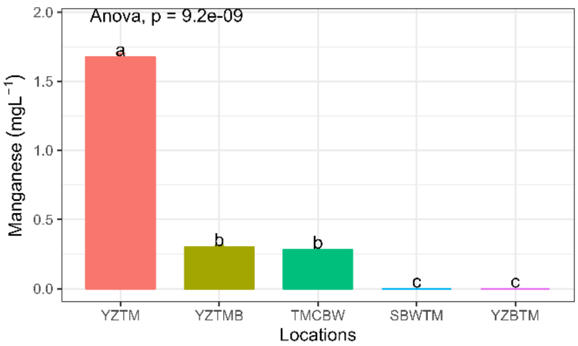
2d: Nitrate content of borehole water samples



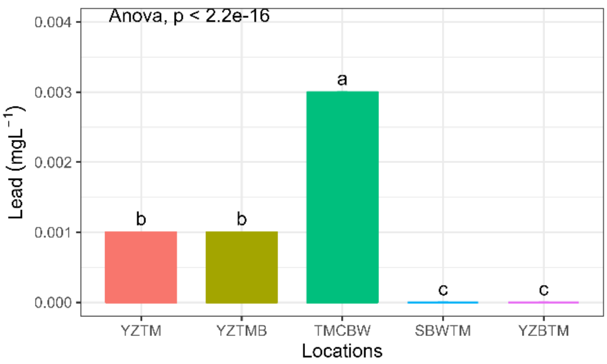
2e: Sulphate content of borehole water samples



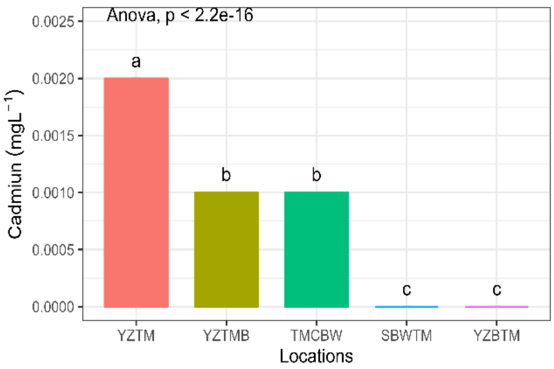
2f: Zinc content of borehole water samples



2g: Manganese content of borehole water samples



2h: Lead content of borehole water samples



2i: Cadmium content of borehole water samples

Table 1: Temperature and copper concentration of borehole water samples

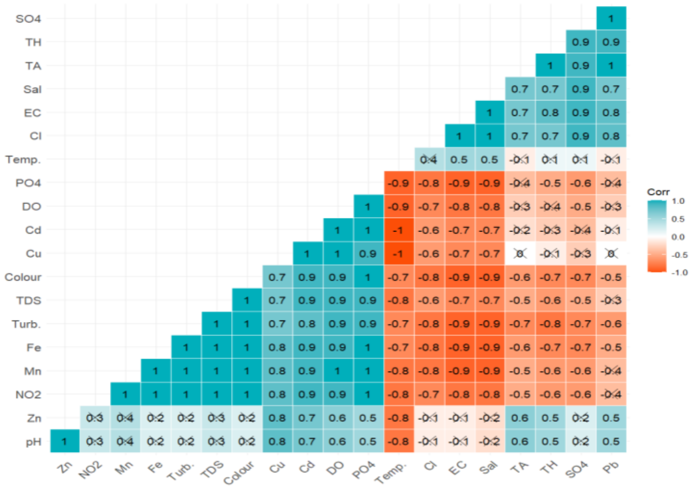
Parameters	**Borehole Samples** YZTM	YZTMB	TMCBW	SBWTM	YZBTM
Temperature (°C)	26.15±0.35a	26.30±0.00a	26.70±0.14a	26.35±0.21a	26.60±0.28a
Copper (mg/ml)	0.022± 0.00a	0.020±0.00b	0.00±0.00d	0.011±0.00c	0.00±0.00d

YZTM = Gwagwalada central, YZTMB = University of Abuja Staff Quarters, TMCBW = Tunje maje, SBWTM = Dobi, YZBTM = Ikwa

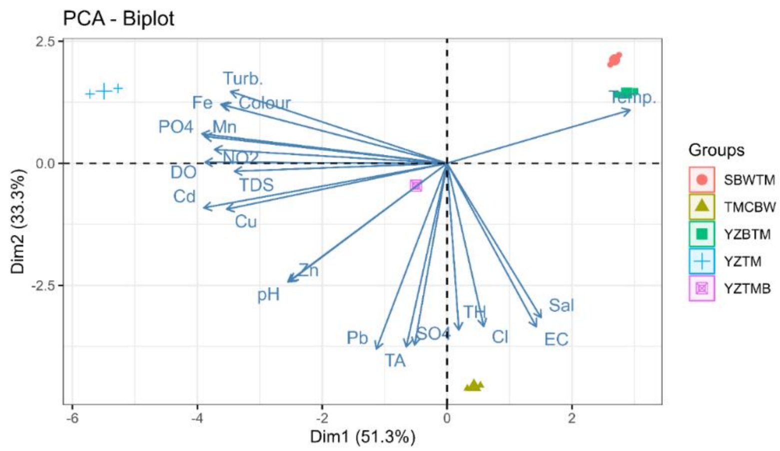
Table 2: Nigerian and WHO guideline values for drinking water samples

Parameter	**Nigerian guideline value**	**WHO guideline value**
Conductivity (µscm-1)	1000	NA
pH	6.5-8.5	6.5-8.0
Total Hardness	250	180
Total Dissolved Solids	NA	NA
Colour (TCU)	NA	15
Turbidity (NTU)	NA	5
Salinity (mg/ml)	NA	NA
Chloride (mg/ml)	250	250
Iron (mg/ml)	0.3	0.3
Zinc (mg/ml)	3.0	NA
Lead (mg/ml)	0.01	NA
Cadmium (mg/ml)	0.003	0.003
Copper (mg/ml)	NA	2.0
Manganese (mg/ml)	0.2	0.4
Phosphate (mg/ml)	NA	NA
Sulphate (mg/ml)	NA	250
Nitrate	50	50

NA = No available guideline



3a: Correlation between physiochemical parameters of borehole water samples from Gwagwalada Area Council of Abuja



3b: Principal component analysis of the interrelationships between physicochemical parameters and sampling locations
EC = Electrical conductivity, **Sal** = Salinity, **Cl** = Chlorine, **TH** = Total Hardness, **SO4** = Sulphate, **TA** = Total Alkalinity, **Pb** = Lead, **Zn** = Zinc, **Cu** = Copper, **TDS** = Total Dissolved Solids, **Cd** = Cadmium, DO = Dissolved oxygen, **NO3-** = Nitrate, **Mn** = Manganese, **PO4** = Phosphate, **Fe** = Iron, **Turb** = Turbidity.

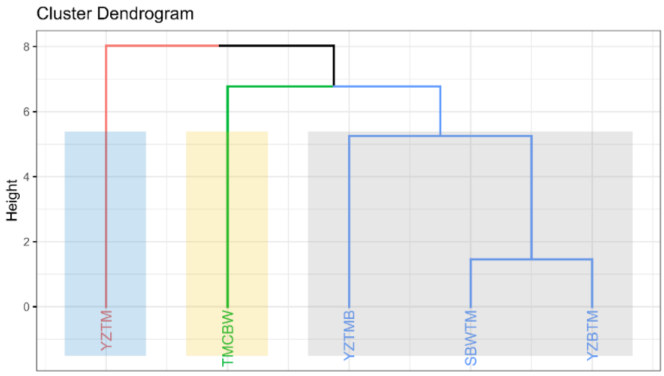


Figure 3c: Cluster dendrogram showing similarities between study locations in relation to physicochemical parameters

Table 3: Biochemical characteristics of bacteria isolates from the borehole samples in Gwagwalada Area Council of the Federal Capital Territory, Abuja

MORPHOLOGICAL CHARACTERISTICS	BIOCHEMICAL REACTION	Suspected Microorganism

Bacterial Code	Gram´ s Reaction	Shape	MR Test	VP Test	Citrate	Catalase	oxidase	Indole test	Urease test	H_2S	Growth onEMB	Sugar ferm.	Glucose	Lactose	PROBABLEID ENTITY
B2	-	Rod	+	+	+	+	-	-	+	+	+	+	+	-	*Proteus spp.*
B2	-	Rod	+	+	+	+	-	-	+	+	+	+	+	-	*Proteus spp.*
C2	-	Rod	-	+	+	+	-	-	-	-	+	+	+	+	*Enterobacter spp.*
C1	-	Rod	-	-	+	+	+	-	-	-	-	+	+	-	*Pseudomonas ssp.*
E	-	Rod	-	+	+	+	-	-	-	-	+	+	+	+	*Enterobacter ssp.*
D3	-	Rod	+	-	-	+	-	+	-	-	GMS	+	+	+	*Escherichia coli*
D1	-	Rod	-	+	+	+	-	-	-	-	+	+	+	+	*Enterobacter spp.*
D2	-	Rod	+	-	-	+	-	+	-	-	GMS	+	+	+	*Escherichia coli*
I2	-	Rod	+	-	-	+	-	+	-	-	GMS	+	+	+	*Escherichia coli*
F2	-	Rod	-	-	-	-	-	-	-	-	-	+	+	+	*Lactobacillus*
F1	-	Rod	+	-	-	+	-	-	-		+	+	+	+	*Shigella*

KEYS:
GMS = Green Metallic Sheen,
+=Positive - = Negative

Table 4: Bacteriological counts of borehole water samples in Gwagwalada Area Council of Abuja

Sample	**Total bacterial count** (cfu/ml)	**Total coliform ount** (MPN/100ml)	**Facal coliform count** (cfu/ml)
YZTM	120	23	80
YZTMB	33	12	0
TMCBW	0	0	0
SBWTM	52	23	35
YZBTM	32	7	80

YZTM = Gwagwalada central, YZTMB = University of Abuja Staff Quarters, TMCBW = Tunje maje, SBWTM = Dobi, YZBTM = Ikwa

Table 5: Occurrence of bacterial species in borehole water samples of Gwagwalada Area Council of Abuja

Sample	*Proteus sp*	*Enterobacter sp*	*Pseudomonas sp*	*Escherichia coli*	*Lactobacillus*	*Shigella*
YZTM	-	-	-	+	+	+
YZTMB	+	+	-	-	-	-
TMCBW	-	-	-	-	-	-
SBWTM	+	+	-	+	-	-
YZBTM	-	+	+	+	-	-

YZTM = Gwagwalada central, YZTMB = University of Abuja Staff Quarters, TMCBW = Tunje maje, SBWTM = Dobi, YZBTM = Ikwa, + = Positive, - = Negative

Table 6: Hospital surveillance for waterborne diseases in Gwagwalada Area Council of Abuja from August 2021 – July 2022

Health Facility	**AGES**			
	< 5 years	5-17 years	18-25 years	26-35 years
	NUMBER OF CASES			
University of Abuja Teaching Hospital	65	7	8	4
Gwagwalada Clinic and Maternity	51	4	18	10
Chitunu Primary Health Care Centre	8	2	0	0
Dukpa Primary Health Care Centre	4	2	2	2
Gwakwo Primary Health Care Centre	13	1	10	7

DISCUSSION

Water temperature is an important element of control strategies against the growth of microorganisms in water. It is recommended to keep the water temperature of the borehole outside the range of 20–28^{o}C. Temperatures between 20 and 28^{o}C for boreholes and 21 and 27^{o}C for well waters promote bacteria growth and proliferation (Pelczar *et al*., 2005; Bello *et al*., 2015; WHO, 2018). In this study, all five borehole water samples collected showed a similar temperature range (26.15–26.70^{o}C). It is possible that the temperature recorded for the borehole water samples facilitated the presence and growth of the bacteria isolates suspected in the borehole water samples in this study. Color is an important physical quality of water that affects the acceptability of water by consumers, while turbidity usually results from the presence of colloidal materials such as clay, silt, and finely divided organic matter in water samples, which provide adsorption sites for chemicals that may be harmful to health or cause undesirable tastes or odors (Adekunle *et al*., 2007). The turbidity, which was almost six times above the WHO permissible level in the YZTM borehole water sample, is an indication of the presence of colloidal solids in the water sample and could translate that the water is unsafe for consumption. Higher turbidity level is associated with higher risk of developing gastrointestinal diseases (Gidado *et al*., 2017). Noticeably, the color of the YZTM borehole water sample was above the WHO permissible threshold. The color in the YZTM water sample, which was above the permissible level, may be a reflection of its turbidity level found to be above the permissible level since the presence of colloidal materials can affect the appearance of water. Additionally, the mineral composition of a borehole site can affect the color of the water, especially if iron compounds are present. It is also possible that the presence of iron, which was detected only in the YZTM, contributed to the color of the borehole water sample. The pH is a measure of the hydrogen ion concentration in a solution. A low pH connotes a high hydrogen concentration (acidic solution), and a high pH connotes a low hydrogen ion concentration. Although the borehole water samples recorded a pH close to neutrality, only the water samples obtained from YZTM (Gwagwalada Central), YZTMB (University of Abuja Staff Quarters), and TMCBW (Tunga Maje Community) scored a pH within WHO and NGV permissible levels. Water samples within the permissible pH level may be suitable for recreational, agricultural, and domestic. However, it is important to note that bacteria, particularly neutrophilic bacteria such as *E. coli* and *Salmonella sp*. can thrive optimally at neutral pH. In the opposite way, pH value of drinking water below 6.5 is associated with ulcer and gastrointestinal irritation as a result of the acidic nature (Jibrin, 2019). The pH range of the borehole samples in this study is in close range with the report of

Unamba *et al*. (2016) and Jibrin (2019) for borehole water samples from Kuje and other area councils of the FCT, Abuja. Salinity measures the amount of dissolved salt in a water. Water bodies with salinity level up to 1000 mg/l are considered to be saline (WHO, 1979). Despite the borehole water samples from the five communities in this study recorded salinity concentrations (Figure 1g), however, these concentrations were statistically ($p>0.05$) insignificant. This implies that all the borehole water samples contain no salt. Although a traceable amount of iron was found in the YZTM water sample and traceable amounts of PO_4, SO_4, NO_3^-, Mn, and Zn, as well as heavy metals such as Pb and Cd in water samples from YZTM, YZTMB, and TMCBW, the presence of Zn, PO_4, NO_3^-, and Mn may not pose a serious health implication on consumers since the concentration of these metals in the water samples was insignificant and far below the permissible limits. Heavy metals such as Pb, Cd, Cu, and Ni although have no bio-importance in human biochemistry and physiology, but consumption even at very low concentrations can be toxic (Arise *et al*., 2015). Generally, while most of the physical properties of the water samples analyzed in this current study were above the recommended threshold, most of the chemical features were within the threshold limit. The findings of Bawa *et al*. (2024) on the physicochemical properties of the source of drinking water for residents of Benue State South Senatorial District, a State that shares same geographical zone with the FCT, Abuja, also showed most chemical features of the source of drinking water to be within the recommended threshold. In Figure 3a, the strength of the correlation among the physiochemical parameters is determined by the R values. The strong positive relationship between the physiochemical variables (i.e., the square box with positive values of 0.5 to 1) indicates a potential common source of contamination, while those with a negative relationship (i.e., the square box with negative values of -0.5 to -1) show that they do not share a common source of contamination. The strong positive relationship which existed between EC, Cl, Sal, TH, and TMCBW (Figure 3b) means that these parameters were higher at TMCBW. Thus, an increase in the levels of these parameters led to a decrease in Pb, Zn, pH, Cu, TDS, Cd, DO, NO_3, PO_4, Fe, Mn, and turbidity. Similarly, turbidity, Fe, Mn, PO_4, NO_3, and color, which showed a positive relationship with the sampling location YZTM in Figure 3b, indicate that these parameters were higher at this location. Temperature, which had a negative relationship with most of the parameters investigated in this study, indicates that with increased temperature, there was a corresponding decrease in the levels of parameters like pH, Zn, Pb, Cu, Cd, DO, and TA. The strong positive relationship between the heavy metals and physicochemical parameters is a strong indication that they are influenced by a common source. Meanwhile, negative relationships observed between the heavy metals show that different sources or non-point sources were responsible for their presence. The SBWTM, YZBTM, and YZTMB borehole water samples, which had similar physiochemical and heavy metal properties at a similarity level of 5 when compared to the other two locations, YZTM and TMCBW, with distinct physicochemical characteristics, and did not form a cluster at 6.0 (Figure 3c), indicate that the stations with similar physiochemical properties can be used as a reference guide for subsequent predictions of water quality. Although the majority of the borehole water samples contained bacterial counts within the acceptable limit of the Nigerian Standard for Drinking Water Quality of 100 cfu/ml (NSDWQ, 2007), except for the bacterial count of the YZTM borehole water sample, which exceeded the Nigerian Standard for Drinking Water Quality of 100 cfu/ml. With the progression of time, certain physiochemical parameters could influence the accumulation of bacteria in the water samples, rendering them unfit for consumption. For instance, a rise in borehole temperature of 20–28^oC can promote bacterial growth and proliferation (Pelczar *et al*., 2005; Bello *et al*., 2015; WHO, 2018). Additionally, the total coliform rule according to WHO requires a maximum concentration of zero for total coliform, fecal coliform, and *E. coli* in drinking water (Hammer and Hammer, 2003). The presence of *E. coli* indicates fecal contamination of the drinking water. The bacterial, coliform, and fecal identification in the borehole water samples may be due to cross-contamination from different sources. The identification of coliform and fecal counts in the borehole samples also rendered them unfit and unsafe for consumption. A previous study by Unamba *et al*. (2016) also reported total coliform count in borehole water samples from six area councils in Abuja. Out of the six genera isolated from the borehole water samples investigated for microbial contamination under this present study, *E. coli* and *Enterobacter* were the most predominant, as they appeared in three out of the five water samples. *E. coli* infection from water samples is known to be associated with diarrhea. These microbes were also reported in borehole water from the study of Unamba *et al*. (2016). Recent study of Odiana *et al*. (2024) also identified *Enterobacter, E. coli* and *Pseudomonas* in borehole water samples collected in five communities of Southern Edo State of Nigeria. The waterborne disease survey from the five health facilities of our study area for the period of one year (August 2021-July, 2022) revealed high prevalence rate of waterborne disease. The prevalence of waterborne disease was predominantly high among children under 5 years old, indicating that children are the most vulnerable to water contamination. Though the hospital surveillance from the health facilities did not reveal the types of waterborne disease predominant in the communities of the study area, it may not be unconnected from microbial contamination of the water possibly due to poor hygiene practice by the residents or other underground water contamination source. According to Yusuff *et al*. (2014) cholera, hepatitis, typhoid, and diarrhea are the most common waterborne diseases in Nigeria.

CONCLUSION

The study concludes that the borehole water samples showed variable physiochemical parameters that were within the permissible range. However, there was microbial contamination in most of the borehole samples, making them unfit for human consumption. Also, surveillance showed a high prevalence of gastrointestinal tract disease in the health facilities of the study area. Thus, the need for interventions that provide portable water or treat the existing water-sources used for drinking as well as increasing the advocacy on good hygiene towards achieving SDG No. 6 and to the prevent outbreak of waterborne diseases that could emanate from the consumption of unsafe water.

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