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Seasonal Assessment of the Physicochemical Quality of Groundwater used for Domestic Purposes at a University Campus in Benin City, Nigeria

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ABSTRACT
The study seasonal assessment of the physicochemical quality of groundwater used for domestic purposes at a university campus in Benin city, Nigeria. A total of 24 water samples were collected during the dry and rainy seasons and analyzed at Martlet Environmental Laboratory. Parameters examined included pH, colour, turbidity, conductivity, total dissolved solids, hardness, chloride, dissolved oxygen, biochemical oxygen demand, calcium, magnesium, zinc, copper and iron.
The results indicated that the water was generally clear and free from detectable turbidity. Most parameters, including conductivity, total dissolved solids, hardness, chloride, dissolved oxygen and biochemical oxygen demand, were within WHO, SON and NAFDAC permissible limits. Iron(fe) was detected, while magnesium generally complied with WHO and NAFDAC standards, although some girls' hostel samples exceeded the SON requirement.
The major concern was the acidic nature of the groundwater, with pH values ranging from 5.0 to 6.0 during the dry season and PH valves ranging 4.0 to 6.0. Conductivity and zinc concentrations increased during the rainy season, possibly due to the infiltration of human waste into the aquifer. Iron concentrations also exceeded NAFDAC and SON limits during the rainy season.
The study concludes that the groundwater requires treatment before consumption, particularly for pH correction. It recommends neutralizer filtration, improved sanitation, proper septic-tank and latrine management, regular cleaning of storage tanks, routine sanitary inspections and further microbiological analysis.

Keywords: Groundwater, drinking water, physicochemical quality, pH, borehole water, WHO, SON, NAFDAC.

INTRODUCTION

Water is an indispensable natural resource and an essential requirement for human survival. It is required for drinking, food preparation, personal hygiene, sanitation, domestic activities, agricultural production and numerous industrial processes (Kumar & Puri, 2021). The availability of sufficient water, however, does not necessarily guarantee that the water is safe for human use. Water quality is equally important because water containing undesirable physical, chemical or microbiological contaminants can create environmental and public-health concerns (Li et al., 2021).

Safe water is particularly important within university environments. Universities accommodate substantial populations of students, lecturers, administrative personnel, maintenance workers and visitors (Akinola et al., 2020). Water is consumed and utilized extensively every day for drinking, cooking, bathing, washing, cleaning and sanitation. Consequently, deficiencies in the quality of water supplied within an institution may affect a large population and can also increase the risk of environmental and public-health problems.(Edokpayi et al., 2020)

In Nigeria, groundwater has become an important alternative source of water because public water-supply systems are not always sufficiently reliable to meet the needs of rapidly growing populations (Olalekan et al., 2022). Boreholes are consequently common in residential areas, schools, hospitals, industries and universities. Groundwater is often considered safer than surface water because it is naturally filtered as it passes through soil and geological formations. Nevertheless, groundwater is not immune to contamination. Assessed groundwater quality in southeastern Nigeria was found elevated concentrations of heavy metals such as iron and lead in several borehole samples, indicating contamination and potential health risks (Egbueri & Unigwe, 2020). Groundwater quality was investigated in Nigeria and reported contamination from nitrates and microbial organisms due to poor siting of boreholes near septic tanks and waste disposal sites. (Nwankwoala & Ngah, 2021). The study did not provide a comprehensive comparison with WHO standards or assess water quality across multiple sources within a single environment. Examined water quality challenges in Nigeria and identified poor infrastructure, weak regulatory enforcement, and inadequate monitoring systems as major contributors to declining water quality and evaluated groundwater quality in southwestern Nigeria, reported elevated levels of physicochemical contaminants influenced by industrial and agricultural activities (Duru & Akinyemi, 2022). The study was largely descriptive and did not involve detailed laboratory-based assessment of water samples or focus on specific institutional environments. The study did not include microbiological analysis or assess the implications of findings in institutional settings such as universities. The quality of sachet water in Nigeria was assessed and found the presence of coliform bacteria in some samples, indicating poor production hygiene and inadequate regulatory compliance (Dada, 2021). The study focused only on packaged water and did not assess other commonly used water sources such as boreholes and wells. So, this study

addresses this knowledge gap by integrating a seasonal assessment of the physicochemical quality of groundwater used for domestic purposes and compared with W.H.O, NAFDAC and SON standard.

MATERIALS AND METHODS

Study Area

The study was conducted at the Legacy Campus of Benson Idahosa University, Benin City, Edo State, Nigeria. The campus is located within Ikpoba-Okha Local Government Area of Edo State, geographically positioned at approximately $6^0$17'59'' North latitude and $5^0$36'16'' East longitude.

The investigation focused particularly on groundwater and associated water-supply facilities serving the university hostels. The investigation involved sampling during both dry and rainy seasons in order to provide information on water quality under different seasonal conditions. Twelve samples were collected during each season, giving a total of 24 samples.

The study area contains borehole water sources, storage facilities and distribution points through which water is supplied to users. The location of groundwater sources in relation to sanitation infrastructure was also considered because septic tanks, latrines and waste-disposal areas can potentially influence groundwater quality.

The study is important because seasonal changes can influence groundwater recharge, infiltration and the movement of contaminants. During periods of rainfall, water can infiltrate the ground and potentially transport substances from the surface into underlying groundwater. The original investigation reported that conductivity increased during the rainy season and associated the increase in metal content with possible infiltration of agricultural and human waste into the surrounding aquifer.

Sampling Points

The various borehole stations with their co-ordinates are given in the table below:

Table 1: The Borehole Stations

S/N	Borehole Station (BS)	Northing ºN	Easting ºE
1	Girls Hostel A (Source)	6°11'18.1"N	5°39'24.8"E
	Girls Hostel Sample 1 (Tank)	6°11'18.2"N	5°39'24.8"E
	Girls Hostel Sample 2 (Tap)	6°11'18.4"N	5°39'25.0"E
2	Girls Hostel B (Source)	6°11'20.9"N	5°39'26.3"E
	Girls Hostel Sample 3 (Tank)	6°11'20.2"N	5°39'25.9"E
	Girls Hostel Sample 4 (Tap)	6°11'20.2"N	5°39'25.9"E
3	Boys Hostel C (Source)	6°20'48.5"N	5°39'25.4"E
	Boys Hostel Sample 5 (Tank)	6°11'22.7"N	5°39'25.7"E
	Boys Hostel Sample 6 (Tap)	6°11'23.2"N	5°39'26.8"E
4	Boys Hostel D (Source)	6°18'22.6"N	5°39'45.1"E
	Boys Hostel Sample 7 (Tank)	6°18'27.6"N	5°39'50.9"E
	Boys Hostel Sample 8 (Tap)	6°18'28.8"N	5°39'51.1"E

Sample Collection

A total of 24 water samples were collected during the investigation. Twelve samples were collected during the dry season, while another twelve were collected during the rainy season. The samples were taken from selected locations within the university hostel water-supply system.

The samples were immediately transported to Martlet Environmental Laboratory, Benin City, for physicochemical analysis.

The use of samples from both seasons allowed the investigation to examine possible seasonal changes in water quality.

Laboratory Analysis

The water samples were subjected to physicochemical analysis. The parameters assessed included:

pH

The pH of the water samples was determined in the laboratory using a Hemma pH meter (Model HI-1922). The meter was first calibrated using a pH 7.0 buffer solution after being rinsed several times with distilled water. 20 ml of each water sample was measured into clean beakers. Each beaker was rinsed with distilled water and then with a small quantity of the sample water to be tested to prevent contamination. For subsequent samples, the beaker was rinsed only with the sample to be analyzed to avoid contamination

Total Dissolved Solids

50 ml of a well-mixed sample was measured into a beaker. The WTW conductivity/ TDS meter probe was immersed in the sample, and its TDS was recorded by pressing the alternate button.

Hardness

Hardness was determined by measuring 50ml of the sample into a 250ml conical flask. 2ml of buffer solution and two drops of Eriochrome Black T indicator was added. The mixture was then titrated with 0.1 M EDTA until a blue colour was obtained.

$$Hardness\ as\ CaCO_3\ mgl = \frac{V \times A \times 1000}{ml\ of\ sample}$$

Where: V= ml titration for sample

A= mg $CaCO_3$ equivalent to 1ml EDTA titrant.

Chloride
Sample volumes of 50ml each was measured into conical flasks. Two drops of potassium heptaoxodichromate (VII) (K_2CrO_4) indicator were added to each flask. The mixtures were then titrated with 0.01 M silver nitrate ($AgNO_3$) solution until a brick-red colour change was observed. A blank titration using only the reagents, without any water sample, was also performed.

Dissolved Oxygen
From the pipettes 1ml of $MnSO_4$ solution was added to the bottle, and also in the same way, 1ml of alkali-iodide-acid solution. Closed with a stopper and well shaken. When the precipitate has settled, 2ml of conc. Sulphuric acid was added to dissolve the precipitate. The released iodine was titrated with 0.025 M sodium thiosulfate.

Calcium and Magnesium
Calcium and Magnesium were determined using the complexometric titration method. To 50ml of the samples, 25ml concentrated ammonia solution, 10 drops of Ca and Mg solution, and 3 drops of erichrome black T were added. This accounts for Ca and Mg that might have been present in 50 mL distilled water taken and the distilled water for reagent preparations. 50ml water sample was added, shaken, and titrated against standard EDTA to a blue endpoint.

EDTA used (A).
For calcium determination:

i. 50 ml of distilled water was placed into a 250 ml Erlenmeyer flask.
ii. 25 ml of 20% KOH solution was added.
iii. 10 drops of Ca and Mg solution and a few grains of 1% calcium indicator were added and shaken.
iv. 50ml of water sample was added to the flask, shaken, and then titrated to a yellow end point used (B).

Volume for mg alone = A-B

$$Ca_l^{mg}() = \frac{400800 \times \mathrm{M} \times \mathrm{B}}{\text{ml sample}}$$

$$Mg_l^{mg}() = \frac{24320 \times \mathrm{M} \times (\mathrm{A} - \mathrm{B})}{\text{ml sample}}$$

Sulphate
The HACH colorimeter (DR/890) was also used in the analysis of sulphate. The instrument was first blanked with 10ml of distilled water after entering the program number (91). The content of one sulphaver 4 sulphate reagent powder pillow was added to 10ml of the sample in the sample cell, mixed by inverting several times, and concentration read from the display screen in mg/l after allowing it to stand for 5 minutes.

RESULTS AND DISCUSSION

Table 2: Results of Chemical Analysis for Dry Season

Code	Ph	EC	Sal.	Col.	Turb.	TSS	TDS	DO	BOD	COD	HCO_3	Na	K	Ca	Mg	Cl	P	NH_4N	NO_2	NO_3	SO_4
		µS/cm	g/l	Pt. Co	NTU			mg/l													
GH SA (Source)	5.7	8	0.004	ND	ND	ND	4	1.3	1.6	6.7	18.0	0.051	0.014	0.180	0.087	15.0	0.041	0.655	0.004	0.006	0.051
GH SA1 (Tank)	5.0	10	0.004	ND	ND	ND	5	1.3	1.5	8.0	18.1	0.055	0.018	0.271	0.102	15.5	0.053	0.770	0.005	0.008	0.110
GH SA2 (Tap)	5.6	18	0.008	ND	ND	ND	9	1.2	1.4	10.8	30.1	0.076	0.026	0.325	0.258	28.1	0.074	0.871	0.010	0.010	0.222
GH SB (Source)	4.8	82	0.037	ND	ND	ND	41	0.9	1.2	18.0	48.8	0.112	0.061	0.778	0.456	41.2	0.201	0.920	0.018	0.018	0.391
GH SB3 (Tank)	5.0	67	0.030	ND	ND	ND	34	1.1	1.3	11.3	36.5	0.087	0.041	0.664	0.401	36.6	0.188	0.890	0.011	0.011	0.232
GH SB4 (Tap)	5.1	11	0.005	ND	ND	ND	6	1.2	1.4	9.7	22.7	0.061	0.022	0.288	0.141	18.0	0.166	0.833	0.007	0.008	0.203
BH SC (source)	5.5	6	0.003	ND	ND	ND	3	1.1	0.7	5.3	15.0	0.038	0.011	0.162	0.101	10.3	0.082	0.691	0.006	0.003	0.110
BH SC5 (Tank)	4.9	8	0.004	ND	ND	ND	4	1.1	0.8	7.4	18.7	0.044	0.018	0.288	0.142	11.4	0.087	0.730	0.008	0.005	0.114
BH SC6 (Tap)	4.8	15	0.007	ND	ND	ND	8	1.0	1.0	8.7	22.7	0.051	0.021	0.207	0.188	18.6	0.088	0.820	0.010	0.007	0.193

Code	Ph	EC	Sal.	Col.	Turb.	TSS	TDS	DO	BOD	COD	HCO_3	Na	K	Ca	Mg	Cl	P	NH_4N	NO_2	NO_3	SO_4
BH SD (Source)	6.3	60	0.027	ND	ND	ND	30	0.7	1.3	13.3	38.6	0.082	0.046	0.456	0.278	38.7	0.211	1.030	0.015	0.015	0.210
BH SD7 (Tank)	6.4	56	0.025	ND	ND	ND	28	0.9	1.1	11.4	28.8	0.064	0.033	0.333	0.221	22.3	0.201	0.991	0.011	0.012	0.210
BH SD8 (Tap)	5.1	9	0.004	ND	ND	ND	5	1.2	0.5	4.1	13.3	0.022	0.008	0.151	0.078	9.7	0.122	0.560	0.004	0.002	0.053
NAFDAC LIMIT	6.5–8.5	1000	N.S	3.0	5.0	1.0	500	<10	5	N.S	100	N.S	10	75	20	100	N.S	N.S	0.02	10.0	100
SON LIMIT	6.5–8.5	1000	N.S	3.0	5.0	1.5	500	<10	5	N.S	100	N.S	10	75	0.20	100	N.S	N.S	0.02	10	100
WHO LIMIT	7.0–8.9	1000	N.S	3.0	5.0	1.0	500	<10	5	N.S	100	N.S	N.S	N.S	20	200	N.S	N.S	0.2	10	250

Key: GH Girls Hostel, BH Boys Hostel, S sample, DO Dissolved Oxygen, EC Electric Conductivity, TDS Total Dissolved solid, TSS Total suspended solid, BOD Biological Oxygen Demand, COD Chemical Oxygen Demand, WHO World Health Organisation, SON Standard Organisation of Nigeria, NAFDAC National Agency for food and drug administration and control

Code		Fe mg/	Mn	Zn	Cu	Cr	Cd	Ni	Pb	V	THC
GH (Source)	SA	0.121	0.042	0.061	0.011	ND	ND	ND	ND	ND	ND
GH (Tank)	SA1	0.123	0.051	0.074	0.018	ND	ND	ND	ND	ND	ND
GH (Tap)	SA2	0.181	0.074	0.101	0.033	ND	ND	ND	ND	ND	ND
GH (Source)	SB	0.221	0.101	0.177	0.064	ND	ND	ND	ND	ND	ND
GH (Tank)	SB3	0.201	0.087	0.164	0.050	ND	ND	ND	ND	ND	ND
GH (Tap)	SB4	0.160	0.056	0.089	0.021	ND	ND	ND	ND	ND	ND
BH (Source)	SC	0.132	0.022	0.101	0.017	ND	ND	ND	ND	ND	ND
BH (Tank)	SC5	0.154	0.038	0.117	0.021	BD	BD	BD	BD	BD	BD
BH (Tap)	SC6	0.171	0.047	0.120	0.025	ND	ND	ND	ND	ND	ND
BH (Source	SD	0.207	0.088	0.153	0.050	ND	ND	ND	ND	ND	ND
BH (Tank)	SD7	0.189	0.062	0.144	0.037	ND	ND	ND	ND	ND	ND
BH (Tap)	SD8	0.120	0.020	0.088	0.015	ND	ND	ND	ND	ND	ND

Code	Fe mg/	Mn	Zn	Cu	Cr	Cd	Ni	Pb	V	THC
NAFDAC LIMIT	0.3	2.0	5.0	1.0	0.05	0.003	N.S	0.01	N.S	N.S
SON LIMIT	0.3	0.05	5.0	1.0	0.05	0.003	N.S	0.01	N.S	N.S
WHO LIMIT	1	0.1	0.01	0.5	0.05	0.003	N.S	0.01	N.S	N.S

Table 3: Results of Chemical Analysis for Rainy Season

Code	Ph	EC	Sal.	Col.	Turb.	TSS	TDS	DO	BOD	COD	HCO_3	Na	K	Ca	Mg	Cl	P	NH_4N	NO_2	NO_3	SO_4
		µS/cm	g/l	Pt.Co	NTU			mg/l													
GHSA (Source	4.4	124	0.056	ND	ND	ND	62	1.3	0.6	10.4	40.3	1.7	2.7	5.4	4.4	44.3	0.074	0.160	0.007	0.086	0.163
GHSA1 (Tank)	4.5	130	0.060	ND	ND	ND	70	1.2	0.9	18.3	60.6	3.2	5.8	9.3	7.1	56.7	0.101	0.217	0.013	0.126	0.217
GHSA2 (Tap)	4.5	128	0.058	ND	ND	ND	65	1.2	0.7	11.7	48.7	2.4	4.1	7.6	5.0	50.1	0.083	0.183	0.008	0.111	0.184
GHSB (Source	4.9	84	0.038	ND	ND	ND	44	1.7	0.7	8.7	33.4	1.5	2.1	5.8	4.0	19.3	0.044	0.083	0.005	0.053	0.071
GHSB3 (Tank)	4.5	154	0.070	ND	ND	ND	79	1.4	1.0	16.6	44.7	2.8	4.7	8.0	6.6	33.7	0.064	0.117	0.009	0.074	0.108
GHSB 4 (Tap)	4.7	130	0.058	ND	ND	ND	67	1.6	0.9	13.0	38.0	1.7	3.0	6.2	4.3	28.4	0.051	0.091	0.007	0.061	0.084
BHSC (Source	4.0	502	0.227	ND	ND	ND	253	1.1	0.5	28.6	66.3	3.3	6.3	14.4	8.4	77.3	0.171	0.417	0.013	0.310	0.330
BHSC5 (Tank)	4.0	528	0.239	ND	ND	ND	266	1.0	0.8	36.1	88.6	5.6	9.7	18.3	11.7	92.9	0.221	0.510	0.024	0.373	0.404
BHSC6 (Tap)	4.4	513	0.232	ND	ND	ND	257	1.1	0.7	33.4	71.4	4.3	8.0	16.7	10.2	80.6	0.184	0.448	0.018	0.313	0.374
BHSD (Source	5.6	50	0.022	ND	ND	ND	27	1.8	0.8	6.0	14.1	0.2	0.5	1.4	0.8	10.3	0.021	0.058	0.002	0.038	0.047
BHSD7 (Tank)	6.3	80	0.036	ND	ND	ND	42	1.5	1.0	10.6	21.4	0.7	1.0	3.7	1.8	18.4	0.038	0.080	0.005	0.061	0.074
BHSD8 (Tap)	7.5	66	0.030	ND	ND	ND	35	1.6	0.9	7.3	17.7	0.5	0.8	2.0	1.1	11.3	0.022	0.062	0.003	0.044	0.061
NAFDAC	6.5	1000	N.S	3.0	5.0	1.0	500	<10	5	N.S	100	N.S	10	75	20	100	N.S	N.S	0.02	10.0	100

Code	Ph	EC	Sal.	Col.	Turb.	TSS	TDS	DO	BOD	COD	HCO_3	Na	K	Ca	Mg	Cl	P	NH_4N	NO_2	NO_3	SO_4
		µS/cm	g/l	Pt.Co	NTU			mg/l													
LIMIT	–																				
	8.5																				
SON LIMIT	6.5 – 8.5	1000	N.S	3.0	5.0	1.5	500	< 10	5	N.S	100	N.S	10	75	0.20	100	N.S	N.S	0.02	10	100
WHO LIMIT	7.0 – 8.9	1000	N.S	3.0	5.0	1.0	500	< 10	5	N.S	100	N.S	N.S	N.S	20	200	N.S	N.S	0.2	10	250

Key: GH Girls Hostel, BH Boys Hostel, S sample, DO Dissolved Oxygen, EC Electric Conductivity, TDS Total Dissolved solid, TSS
Total suspended solid, BOD Biological Oxygen Demand, COD Chemical Oxygen Demand, WHO World Health Organisation, SON Standard Organisation of Nigeria, NAFDAC National Agency for food and drug administration and control

Code	Fe mg/l	Mn	Zn	Cu	Cr	Cd	Ni	Pb	V	THC
GH SA (Source	0.328	0.121	0.170	0.055	ND	ND	ND	ND	ND	ND
GH SA1 (Tank)	0.281	0.093	0.140	0.043	ND	ND	ND	ND	ND	ND
GH SA 2 (Tap)	0.301	0.112	0.153	0.052	ND	ND	ND	ND	ND	ND
GH SB (Source	0.328	0.128	0.210	0.077	ND	ND	ND	ND	ND	ND
GH SB3 (Tank)	0.303	0.107	0.181	0.060	ND	ND	ND	ND	ND	ND
GH SB4 (Tap)	0.312	0.114	0.193	0.071	ND	ND	ND	ND	ND	ND
BH SC (Source	0.291	0.107	0.133	0.048	ND	ND	ND	ND	ND	ND
BH SC5 (Tank)	0.212	0.086	0.113	0.032	ND	ND	ND	ND	ND	ND
BH SC6 (Tap)	0.228	0.091	0.128	0.041	ND	ND	ND	ND	ND	ND
BH SD (Source	0.352	0.148	0.236	0.099	ND	ND	ND	ND	ND	ND
BH SD7 (Tank)	0.327	0.121	0.201	0.074	ND	ND	ND	ND	ND	ND
BH SD8 (Tap)	0.341	0.133	0.222	0.083	ND	ND	ND	ND	ND	ND
NAFDAC LIMIT	0.3	2.0	5.0	1.0	0.05	0.003	N.S	0.01	N.S	N.S
SON LIMIT	0.3	0.05	5.0	1.0	0.05	0.003	N.S	0.01	N.S	N.S

Code	Fe mg/l	Mn	Zn	Cu	Cr	Cd	Ni	Pb	V	THC
WHO LIMIT	1	0.1	0.01	0.5	0.05	0.003	N.S	0.01	N.S	N.S

General Physicochemical Quality

The laboratory investigation showed that several of the assessed parameters were within the applicable limits referenced in the study. The results indicated that the sampled water had acceptable colour characteristics and that no turbidity was detected in the samples.

Conductivity values were reported to be below the applicable permissible limits. The presence of conductivity indicates dissolved ionic substances in the groundwater, although the measured values were considered acceptable in relation to the standards used in the study.

Total dissolved solids were also reported to be below the acceptable limits specified by WHO, SON and NAFDAC.

Similarly, all samples were reported to comply with the hardness limits referenced in the study.

The chloride results were also reported to be below the limits specified by WHO, SON and NAFDAC.

pH

The most significant water-quality concern identified in the investigation was pH.

The reported pH values ranged from 4.3 to 6.0. The original study interpreted these results as indicating that the groundwater was acidic and reported that the pH values fell below the minimum recommended values used for comparison in the project.

Frome Table 1, dry-season analysis similarly reported that the pH values (4.8-6.4) from the investigated locations fell below the minimum values referenced by WHO, SON and NAFDAC in the project (WHO 7.0-8.9, SON 6.5-8.5 and NAFDAC 6.5-8.5)

From Table 2, the rainy-season pH results (4.0-6.3) also indicated acidic groundwater.

This finding is important because acidic water can have implications for water distribution systems and can influence the behaviour of dissolved substances. It therefore represents the principal treatment concern identified by the study.

Conductivity and Total Dissolved Solids

The conductivity values obtained during the dry season were reported to be below the applicable limits. The study noted that the presence of conductivity indicates dissolved salts in the borehole water.

Total dissolved solids also fell below the acceptable limits referenced in the study.

From Table 1, during the rainy season, conductivity increased compared with the dry season, although the values remained below the referenced WHO, SON and NAFDAC guideline limits. The study associated the seasonal increase with increased metal content and possible infiltration human waste through rainfall and flooding into the surrounding aquifer.

Hardness, Chloride and Oxygen Parameters

All samples were reported to meet the referenced hardness limits.

Chloride concentrations were also below the referenced WHO, SON and NAFDAC limits.

Dissolved oxygen results were reported to comply with the limits used by the study.

Biochemical oxygen demand results were also reported to be below the maximum permissible limits used for comparison.

Calcium and Magnesium

No calcium was detected in the tested samples according to the original study.

Magnesium concentrations generally met the WHO and NAFDAC guidelines. However, the study reported that the Girls Hostel GHSB source and GHSB3 tank did not meet the SON standard.

This finding suggests that although most magnesium results were within the referenced requirements, specific sampling points may require additional attention.

Zinc, Copper and Iron

The study reported that from Table 1, zinc ranges from (0.101-164), copper (0.011-0.064) and iron (0.171-0.221) concentrations during the dry season were below the acceptable limits referenced for NAFDAC and SON, while also noting their relationship to the WHO standard.

During the rainy season Table 2, zinc concentrations increased compared with the dry season. The study reported that the samples remained below the NAFDAC and SON limits used in the research.

Copper concentrations were lower during the rainy season than during the dry season and were reported to remain below the NAFDAC and SON limits used in the project.

Iron presented a more important seasonal concern. The study reported that during the rainy season, iron values exceeded the acceptable limits referenced for NAFDAC and SON, although they were below the WHO value used in the study.

Discussion

Significance of the Acidic Groundwater

The principal concern identified by this investigation is the acidic condition of the groundwater. The pH range of 4.3–6.0 indicates that the groundwater is on the acidic side.

The project concluded that the water should not be consumed untreated and recommended treatment to remove the acidic nature.

From an engineering perspective, pH is an important water-quality parameter because it can influence the interaction between water and distribution infrastructure. Acidic water may contribute to corrosion and may affect the dissolution and transport of certain substances.

The acidic condition may also help explain why monitoring of metallic constituents is important. The presence and mobility of metals in groundwater can be influenced by water chemistry. Consequently, pH adjustment should form part of the proposed treatment strategy.

Seasonal Variation

The comparison of dry- season and rainy-season results provides evidence that seasonal conditions influence some characteristics of the groundwater.

Conductivity values ranges from 50-528 µS/cm was higher during the rainy season than during the dry season (6-60 µS/cm), although the measured values remained below the limits referenced in the study.

Similarly, from Table 2, zinc concentrations were higher during the rainy season when compare to Table 1, dry season while copper concentrations were lower than those observed during the dry season.

The increase in metal concentrations during the rainy season (Table 2) may be associated with increased infiltration and movement of substances from the surface into the groundwater system. The original study specifically associated increased metal content with infiltration of human waste through floodwater into the surrounding aquifer.
This observation highlights the importance of proper environmental sanitation around groundwater sources.

Environmental Sanitation and Groundwater Protection
Groundwater quality is closely connected with activities occurring around the water source. Poor waste management, poorly located septic tanks and inadequate sanitation can increase the risk of groundwater contamination.
The original study therefore recommends educating the university community on environmental cleanliness, waste management and appropriate management of latrine and septic-tank locations.
This recommendation is particularly relevant in a university environment because large populations generate substantial quantities of domestic wastewater and solid waste. Effective management of these wastes is therefore necessary to protect groundwater resources.

Importance of Water-Storage Facilities
Water quality does not necessarily remain unchanged after abstraction from a borehole. Storage tanks and distribution systems can influence water quality through sediment accumulation, poor cleaning, corrosion or other operational problems.
The original research recommends that storage tanks should be cleaned according to an established water-safety maintenance programme to remove impurities.
Although the exact cleaning frequency should ideally be determined through a documented water-safety and maintenance programme, the study's recommendation highlights the importance of maintaining storage facilities as part of the overall water-supply system.

Conclusion
This study assessed the physicochemical quality of groundwater and associated water-supply sources at the Legacy Campus of Benson Idahosa University, Benin City, Nigeria.
A total of 24 water samples were collected, comprising 12 dry-season and 12 rainy-season samples, and subjected to laboratory analysis. The investigation assessed a range of physicochemical parameters and compared the results with WHO, SON and NAFDAC standards.
The results indicate that most of the tested parameters were within the applicable limits referenced in the study. Colour was within permissible limits, turbidity was not detected, conductivity and total dissolved solids were below the referenced limits, and hardness and chloride were also reported to be within acceptable levels.
However, pH was identified as the major water-quality concern. The reported pH values ranged from 4.3 to 6.0, indicating acidic groundwater.
Seasonal variations were also observed. Conductivity was higher during the rainy season, zinc concentrations increased during the rainy season, and iron was reported to exceed the NAFDAC and SON limits during the rainy season.
The findings demonstrate that groundwater quality within a university environment requires continuous monitoring and appropriate management. The fact that water may be visually clear does not eliminate the need for laboratory testing and sanitary inspection.
The study therefore recommends that the borehole water be appropriately treated before consumption, with particular attention to neutralizing its acidic condition. A neutralizer filtration system should be considered at the storage stage, while environmental sanitation, waste management and the positioning of septic systems should be improved. Storage tanks should be cleaned regularly, and a dedicated water-quality evaluation team should conduct routine sanitary inspections.
Finally, microbiological analysis should be incorporated into future investigations because the original study was unable to perform this aspect of water-quality assessment.
The overall evidence demonstrates that effective water-quality management at Nigerian universities should adopt a preventive approach based on regular monitoring, appropriate treatment, environmental sanitation and proper maintenance of water-supply infrastructure.

Recommendations
Based on the results of the investigation, the following recommendations are made.
Treatment Before Consumption
The borehole water should be appropriately treated before it is supplied for drinking. The treatment system should specifically address the acidic condition identified by the investigation.

Installation of a Neutralizer Filtration System
A neutralizer filtration system should be installed at an appropriate point in the water-supply system, particularly before water is distributed from the storage tank for consumption. This recommendation is directly supported by the original study.

Improved Waste Management
The university should strengthen environmental sanitation and waste-management practices around groundwater sources. Special attention should be paid to the location and maintenance of septic tanks, soakaways and latrines.

Regular Cleaning of Storage Tanks
Storage tanks should be cleaned regularly to prevent accumulation of impurities. The original study recommends cleaning at least twice each month.

Establishment of a Water-Quality Evaluation Team
The university should establish a water-quality evaluation team responsible for regular sanitary inspection and monitoring of the entire water-supply system.

Routine Laboratory Testing
Physicochemical testing should be conducted periodically, with additional sampling during both dry and rainy seasons. This will help identify changes in groundwater quality and provide an early warning of deterioration.

Protection of Borehole Sources
Boreholes should be protected from potential contamination sources through proper site planning, drainage control, sanitation and waste management.

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Appendixes

WHO Drinking Water Quality Standards

Parameter	Unit	WHO Standard
Temperature	°C	Ambient
pH	-	6.5 – 8.5
Electrical Conductivity	µS/cm	≤1000
Total Dissolved Solids	mg/L	≤500
Turbidity	NTU	≤5
Dissolved Oxygen	mg/L	≥5 (desirable)
Biochemical Oxygen Demand	mg/L	Not specified
Chemical Oxygen Demand	mg/L	Not specified
Salinity	mg/L	≤600 (desirable)
Calcium	mg/L	≤75
Magnesium	mg/L	≤50
Iron	mg/L	≤0.3
Zinc	mg/L	≤3.0
Chloride	mg/L	≤250
Sulphate	mg/L	≤100
Nitrate	mg/L	≤50
Lead	mg/L	≤0.01
Cadmium	mg/L	≤0.003
Total Coliform	CFU/100 mL	0
E. coli	CFU/100 mL	0

Table 2.2: SON (NIS 554:2015) Drinking Water Quality Standards

Parameter	Unit	SON Standard
Temperature	°C	Ambient
pH	-	6.5 – 8.5
Electrical Conductivity	µS/cm	≤1000
Total Dissolved Solids	mg/L	≤500
Turbidity	NTU	≤5
Dissolved Oxygen	mg/L	Not specified
Biochemical Oxygen Demand	mg/L	Not specified
Chemical Oxygen Demand	mg/L	Not specified
Salinity	mg/L	Not specified
Calcium	mg/L	≤75
Magnesium	mg/L	≤50
Iron	mg/L	≤0.3
Zinc	mg/L	≤3.0
Chloride	mg/L	≤250
Sulphate	mg/L	≤100
Nitrate	mg/L	≤50
Lead	mg/L	≤0.01
Cadmium	mg/L	≤0.003
Total Coliform	CFU/100 mL	0
E. coli	CFU/100 mL	0

Source: Standards Organisation of Nigeria (2015). Nigerian Standard for Drinking Water Quality (NIS 554:2015).

Table 2.3: NAFDAC Drinking Water Quality Standards

Parameter	Unit	NAFDAC Standard
Temperature	°C	Ambient
pH	-	6.5 – 8.5
Electrical Conductivity	µS/cm	≤1000
Total Dissolved Solids	mg/L	≤500
Turbidity	NTU	≤5
Dissolved Oxygen	mg/L	Not specified
Biochemical Oxygen Demand	mg/L	Not specified
Chemical Oxygen Demand	mg/L	Not specified
Salinity	mg/L	Not specified
Calcium	mg/L	≤75
Magnesium	mg/L	≤50
Iron	mg/L	≤0.3
Zinc	mg/L	≤3.0
Chloride	mg/L	≤250
Sulphate	mg/L	≤100
Nitrate	mg/L	≤50
Lead	mg/L	≤0.01
Cadmium	mg/L	≤0.003
Total Coliform	CFU/100 mL	0
E. coli	CFU/100 mL	0

Source: National Agency for Food and Drug Administration and Control (2018). Guidelines for Packaged Drinking Water.

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