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Campus groundwater quality index of Akperan Orshi Polytechnic Yandev

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Abstract

Ten sources of groundwater of Akperan Orshi Polytechnic, Yandev, Gboko, Benue State, Nigeria, covering 5 boreholes and 5 shallow wells were analysed for 21 physico-chemical parameters and coliforms using standard methods. The data obtained from the analysis were subjected to a two-tailed T-Test and showed no significant difference ($p > 0.05$). The concentrations of the parameters were compared with World Health Organization (WHO) permissible limits. The contamination of iron above the WHO permissible level of 0.30 mg/L was recorded in 7 out of 10 water resources. Manganese was detected in only three shallow wells with SW2 having a value of 0.0972 mg/L above the WHO permissible level of 0.05 mg/L. Lead was detected in only two (2) shallow well water resources with SW2 having a value of 0.0936 mg/L which is above the WHO permissible level of 0.05 mg/L. Only SW2 had an estimated total coliform value of 2 MPN index/100 mL and faecal/thermotolerant coliform value of 1 MPN index/100 mL above the WHO limit. SW2 poses a health risk as it is the only water source that is contaminated with Fe, Mn, Pb, total and thermo tolerant coliforms above the WHO permissible levels. SW2 is uncovered and without a stage and wall head, making it liable to seepage of run-off water. The estimated Water Quality Index (WQI) for the borehole water (BH) was 32 and shallow well water (SW) was 48, showing excellent water quality for both, though, based on the values, the quality of BH is better.

Keywords: Groundwater, physico-chemical, borehole, shallow well, coliform

Introduction

Water for household consumption should be safe and acceptable. Safe drinking-water, as defined by the Guidelines of World Health Organization, WHO, is water which does not present any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. Water which is meant for household use must be of good quality. The great majority of evident water-related health problems are as the result of chemical and microbial (bacteriological, viral, protozoan or other biological) contamination. The pathogens that may be transmitted through contaminated drinking-water are diverse (WHO, 2022) ^[27]. Most chemicals arising in drinking-water are of health concern only after extended exposure for years, rather than months. Significant problems, even crises, can occur, when chemicals posing high health risk are widespread but their presence is unknown; because their long-term health effect is caused by chronic exposure as opposed to acute exposure (WHO, 2023) ^[28]. The concentration at which constituents are objectionable to consumers is variable and dependent on individual and local factors, including the quality of the water to which the community is accustomed with and a variety of social, environmental and cultural considerations. Guideline values have not been established for constituents influencing water quality which have no direct links to adverse health impacts (WHO, 2022) ^[27].

Providing safe drinking water is one of the most complex challenges facing African rural communities. Increased human activities (urbanization, industrialization, agriculture, open grazing and domestic activities have not only rendered most water bodies (streams, lakes, rivers, ponds, dams, open wells and canals) unfit for domestic purposes, but breeding ground for most deadly pathogens. As a result of industrialization and urbanization, people migrate to townships and the populations in these cities become too high; so is the need for water.

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It is pertinent to observe that there are several human activities, which have indirect and devastating effects on ground water quality. Such activities include accidental or unauthorized release of chemical substances; discharge of untreated effluents, leaching of noxious liquids from solid waste deposits, surface runoff, discharge of untreated sewage, operation of un-authorized dumpsite from people around the area. These pollutants or contaminants are carried by water and water moves easily (percolates) through the soil and underlying rocks. Percolation occurs particularly where the soil is sandy, consists of gravels, or is porous like limestone bedrock (Wuave, 2024) [29].

Government of most countries of the world, claim to provide water for her populace. But where portable water supply is provided, the supplies are unreliable and insufficient; forcing residence to reverse to traditional and contaminated water sources. It is therefore imperative to monitor the physico-chemical and microbial quality of water supply in rural areas in other to highlight the quality of water supply and to provide the impetus for sustained government intervention (Essamlali, Nhaila & El Khaili, 2024) [15]. Water from all boreholes and wells for human consumption ought to meet the standards laid down by World Health Organization for drinking water to make the water potable. Improving access to safe drinking-water can result in tangible benefits to health. According to American Water Works Association, (AWWA), the quality of water is determined according to its physical, chemical and biological parameters (AWWA, 2013) [6]. Water analysis is therefore very important aspect of water-use culture. Every effort should therefore, be made to achieve a drinking-water quality as safe as practicable and one of the ways of improving access to safe drinking-water is through water analyses.

Materials and Methods

Sample Collection: Ten (10) samples of water consisting of five (5) samples from boreholes and five (5) samples from shallow wells were collected from various locations in Akperan Orshi Polytechnic, Yandev, Gboko, Benue State, Nigeria, following standard procedures.

Methods of Analysis

Water samples collected were analysed by both classical and instrumental methods prescribed by standard methods for the analysis of water, following Standard Operating Procedures (SOPs).

Electrical conductivity was determined using a digital conductivity meter, turbidity was determined using a digital turbidity meter, TOTAL SOLIDS (TS) was determined using gravimetric analysis, Total Dissolved Solids (TDS) was determined using gravimetric analysis, pH was determined using a digital pH meter which was determined at the point of sampling because pH changes or fluctuates with time, alkalinity was measured using titrimetry, total hardness was measured using titrimetry, calcium hardness was measured using titration and magnesium hardness was measured using titration. Sulphate was determined by back titration method with magnesium chloride using Eriochrome Black T indicator, nitrate was determined by the phenoldisulphonic acid method, chloride content was determined by Mohr's or Argentometric method (precipitation). Metals were determined through instrumental methods using Atomic Absorption Spectrophotometer (AAS). The metals determined here are classified into three groups. These include; heavy metals, alkaline earth metals and alkali metals. Wet-oxidation method called Walkey-Black method was used for this analysis. The method is not suitable for the determination of volatile organic constituents (International Organization for Standardization, 2023; APHA, 2022; APHA-AWWA-WEF, 1999) [5]. The analysis covered total and thermotolerant coliform (most often called faecal coliform). Coliform bacteria and was determined using Most Probable Number (MPN) method (APHA-AWWA-WEF, 1999) [5].

Data analysis

The data was analysed using T-Test; comparing the mean values of borehole water resources with shallow well water resources. The overall water quality was estimated using Water Quality Index (WQI).

Results

Table 1: Result of all ground water resources in AOPOLY

Parameters (Unit)	BH1	BH2	BH3	BH4	BH5	SW1	SW2	SW3	SW4	SW5	WHO Permissible level
Elect. Cond. ($\mu\text{S}/\text{cm}$)	366.0	440.0	128.3	115.8	161.9	411.0	105.3	121.7	550.0	660.0	1000
Turbidity (NTU)	0.10	0.20	0.20	0.10	0.10	0.20	0.10	0.10	0.50	0.40	5
TS (mg/L)	220.0	240.0	220.0	320.0	220.0	240.0	220.0	440.0	160.0	140.0	1000
TDS (mg/L)	200.0	200.0	200.0	300.0	200.0	200.0	200.0	400.0	100.0	80.0	1000
TSS (mg/L)	20.0	40.0	40.0	20.0	20.0	40.0	20.0	40.0	60.0	60.0	500
pH	6.3	6.7	6.2	6.4	6.4	6.0	6.4	6.6	7.5	6.6	6.0-8.5
Alkalinity (mg/L)	32.0	26.8	30.8	27.2	22.0	26.0	24.0	38.0	36.0	48.0	100
Total hardness (mg/L)	52.80	49.28	66.88	70.40	79.20	135.52	56.32	126.72	40.48	19.36	500
Ca hard. (mg/L)	18.30	10.56	20.42	18.30	17.60	113.34	11.26	24.64	12.67	5.63	500
Mg hardness (mg/L)	1.69	5.49	3.80	5.91	8.45	126.30	6.76	15.63	2.11	1.27	500
Sulphates (mg/L)	9.60	10.56	10.56	11.52	10.56	10.56	9.60	18.24	7.68	5.76	200-400
Nitrate (mg/L)	8.39	11.89	10.49	13.29	12.59	11.89	9.09	22.38	6.99	6.29	50
Chloride (mg/L)	29.94	11.36	21.30	22.69	22.69	18.43	31.20	68.10	15.60	17.04	200-250
Fe (mg/L)	0.1223	0.2445	0.4891	0.6114	0.2148	0.8559	2.5677	0.5013	0.5013	0.6445	0.30
Mn (mg/L)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0324	0.0972	0.0000	0.0388	0.0000	0.05
Pb (mg/L)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0489	0.0936	0.0000	0.0000	0.0000	0.05
Ca (mg/L)	1.3333	2.0000	3.3333	4.0000	15.3333	14.0000	66.0000	16.6667	0.6667	2.0000	200
Mg (mg/L)	2.2545	0.8454	3.6924	3.1432	3.5623	3.6201	5.9179	4.1259	1.2428	2.4495	150
Na (mg/L)	0.0447	0.2056	0.5140	0.9832	4.0262	1.8816	4.4291	4.0822	3.4511	2.7441	250
K (mg/L)	0.0773	0.1547	0.2320	0.3094	4.4970	7.3481	21.0387	18.1364	3.3727	3.6909	50
Total Organic C (%)	0.58	0.95	0.65	0.72	1.20	1.01	0.74	0.65	0.74	0.74	1.0
Total coliform (MPN index/100 ml)	<1	<1	<1	<1	<1	<1	2	<1	<1	<1	0 or <1
Faecal Coliform (MPN index/100 ml)	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	0 or <1

BH=Borehole, SW=Shallow Well

Water Quality Index (WQI)**Table 2:** Table of assigned and relative weights for parameters in estimation of WQI

S/No	Parameters (units)	WHO Permissible level	Assigned weights for each parameter (w_i)	Relative weights for each parameter (W_i)
1	Elect. Cond. ($\mu\text{S}/\text{cm}$)	1000	4	0.06060
2	Turbidity (NTU)	5	2	0.03030
3	Total solids (mg/L)	1000	4	0.06060
4	TDS (mg/L)	1000	4	0.06060
5	TSS (mg/L)	500	2	0.03030
6	pH	7.2	4	0.06060
7	Alkalinity (mg/L)	100	3	0.04545
8	Total hard. (mg/L)	500	2	0.03030
9	Ca hard. (mg/L)	500	2	0.03030
10	Mg hard. (mg/L)	500	2	0.03030
11	Sulphate (mg/L)	300	4	0.06060
12	Nitrate (mg/L)	50	5	0.07575
13	Chloride (mg/L)	225	3	0.04545
14	Iron content (mg/L)	0.30	4	0.06060
15	Mn (mg/L)	0.05	4	0.06060
16	Pb (mg/L)	0.05	5	0.07575
17	Ca (mg/L)	200	2	0.03030
18	Mg (mg/L)	150	2	0.03030
19	Na (mg/L)	250	4	0.06060
20	K (mg/L)	50	2	0.03030
21	Total C (%)	1.0	2	0.03030
			$\sum w_i=66$	$\sum W_i=1$

Table 3: Calculation of water quality index for borehole water resources

S/No	Parameters	BH ave. value	$Q = \frac{\text{average value}}{\text{WHO value}} \times 100$	$(SI_i = (W_i \times Q_i))$
1.	Elect. cond.	242.4	24.2	1.5
2.	Turbidity	0.14	2.80	0.08
3.	Total solids	244.0	24.4	1.5
4.	TDS	220.0	22.0	1.3
5.	TSS	28.0	5.6	0.2
6.	pH	6.4	88.9	5.4
7.	Alkalinity	27.8	27.8	1.3
8.	Total hardness	63.71	12.74	0.39
9.	Calcium hard.	17.03	3.41	0.10
10.	Mg hardness	5.07	1.01	0.03
11.	Sulphate	10.56	3.52	0.21
12.	Nitrate	11.33	22.66	1.72
13.	Chloride	21.60	96.00	4.36
14.	Iron content	0.3364	112.1333	6.7953
15.	Manganese	0.0000	0.0000	0.0000
16.	Lead	0.0000	0.0000	0.0000
17.	Calcium	5.2000	2.6000	0.0788
18.	Magnesium	2.7000	1.8000	0.0545
19.	Sodium	1.1547	0.4619	0.0280
20.	Potassium	1.0541	2.1082	4.4445
21.	%Total carbon	0.82	82.00	2.48
			$WQI = \sum SI_i =$	$31.9711 \approx 32 = \text{Excellent}$

Table 4: calculation of water quality index for shallow well water resources

S/No	Parameters	BH ave. value	$Q_i = \frac{\text{ave. value}}{\text{WHO value}} \times 100$	$(SI_i = (W_i \times Q_i))$
1.	Electrical conduc.	369.6	37.0	2.2
2.	Turbidity	0.26	5.20	0.16
3.	Total solids	240.0	24.0	1.5
4.	TDS	196.0	19.6	1.2
5.	TSS	44.0	8.8	0.3
6.	pH	6.6	91.7	5.6
7.	Alkalinity	149.6	34.4	1.6
8.	Total hardness	75.68	15.14	0.46
9.	Calcium hard.	33.51	6.70	0.20
10.	Mg hardness	30.41	6.08	0.18
11.	Sulphate	10.37	3.47	0.21
12.	Nitrate	11.33	22.66	1.72
13.	Chloride	30.07	13.36	0.61
14.	Iron content	1.0141	338.0333	20.48
15.	Manganese	0.0337	67.4000	4.0844
16.	Lead	0.0285	57.0000	4.3178
17.	Calcium	19.8667	9.9334	0.3010
18.	Magnesium	3.4712	2.3141	0.0701
19.	Sodium	3.3176	1.3270	0.0804
20.	Potassium	10.7174	21.4348	0.6495
21.	%Total carbon	0.78	78.00	2.36
			$WQI = \sum SI_i =$	$48.2832 \approx 48 = \text{Excellent}$

Table 5: A table of water quality index categories

WQI	Categories (water quality statements)
≤50	Excellent
51-100	Good
101-200	Poor
201-300	Very poor
>300	Unfit for drinking (very bad)

Discussion of Result

The results of the analysis were compared with the World Health Organization (WHO) permissible limits, highlighting potential health implications.

Electrical Conductivity

The levels electrical conductivity for all the water samples was below WHO permissible level of 1000 $\mu\text{S}/\text{cm}$. The average electrical conductivity in shallow well water with calculated to be 369.6 $\mu\text{S}/\text{cm}$ was higher than the average of borehole water with a value of 242.4 $\mu\text{S}/\text{cm}$. The values for borehole water sources ranged from 115.8 $\mu\text{S}/\text{cm}$ to 440.0 $\mu\text{S}/\text{cm}$ while, the range for shallow well water resources ranged from 105.3 $\mu\text{S}/\text{cm}$ to 660.0 $\mu\text{S}/\text{cm}$. Low values of conductivity have been reported in ground water in Gboko, Benue State. The low values of conductivities are as a result of the low values of total dissolved solid especially, the dissolved salts (Okoye & Nyietagher, 2009) ^[22].

Turbidity

The values for turbidity for all samples were below WHO permissible level of 5 NTU. SW4 recorded the highest value of 0.50 NTU. The average value for shallow well water resources with the value of 0.26 NTU was higher than the average value for borehole water resources with the value of 0.14 NTU. Low values of turbidity have been reported in groundwater in Gboko, Benue State. Low values of turbidity can only be observed in properly built or protected wells or wells which receive seepage of runoff water (Chukwu, Chime, Okoro Ahmadu, 2022) ^[11].

Solids in water

All the values for TS, TDS and TSS were all below the WHO permissible level of 1000 mg/L, 1000 mg/L and 500 mg/L respectively. The trend here showed TS>TDS>TSS. The average values were generally higher in shallow well water resources than the borehole water resources. Shallow well water resources has the following average values of 240.0 mg/L and 196.0 mg/L for TS and TDS which were lower than the average values for borehole water resources of 244.0 mg/L and 220.0 mg/L for TS and TDS though, the average value for TSS in shallow well water resources 44.0 mg/L was higher in value than the average value of TSS in borehole water resources with an average value of 28.0 mg/L. Low values of solids have been reported in groundwater in Gboko, Benue State (Okoye & Nyietagher, 2009) ^[22]. The general low values of total solids in water correlated with low values of electrical conductivity as low amount of dissolved solids results in low conductivity (Ovem, Ovem & Ezeweali, 2014) ^[24].

pH Levels

The pH levels were all within the WHO range of 6.0-8.5. The average value for shallow water resources of 6.6 was higher than that of borehole water resources which was 6.4.

The low average pH values of the water resources are consistent with published studies, which indicate that the pH of ground waters in Nigeria were predominantly acidic. If pH values are higher than the permissible limit, the water is hard. Hard water is not harmful for consumption but wastes soap. Reported values include: an average of 6.00 to 6.45 in Gboko (Akertyo, Onah, Adimanyi & Nyajo, 2024) ^[2], 4.3 to 7.8 in Lagos, 4.8 to 5.1 in Onitsha, an average of 5.5 in Benin and 5.5 to 7.2 in Akure; this signifies soft water (Okoye & Nyietagher, 2009) ^[22].

Alkalinity levels

All the values for alkalinity were below the WHO limit of 100 mg/L. For all the water resources, the range was 22.0 mg/L for BH3 to 48.0 mg/L for SW5. The calculated average value of alkalinity was higher in shallow well water resources (34.4 mg/L) than in borehole water resources (27.8 mg/L). Low values of groundwater alkalinity have been reported in Enugu State, which is a state near Benue State and the low values of alkalinity means that the hardness of water is low (Edeonovo, 2010) ^[13].

Hardness levels

Total hardness, Ca hardness and Mg hardness were determined. The values for total hardness, Ca hardness and Mg hardness were all respectively below the WHO permissible level of 500 mg/L. The general trend showed Total hardness>Ca hardness>Mg hardness. The average values of well water resources were higher than the average values borehole water resources. For shallow well water resources, the values were, 75.68 mg/L for total hardness, 33.51 mg/L for Ca hardness and 30.41 mg/L for Mg hardness, which were higher than the corresponding values for borehole water resources of 63.71 mg/L for total hardness, 17.04 mg/L for Ca hardness and 5.07 mg/L for Mg hardness. High values of hardness causes the attendant problems which are associated with hard water which are; rheumatic pains, cardiovascular diseases, gouty conditions Others effects of hardness of water are; hardening of vegetables, production of deposits and scaling on pipes and boilers and wastage of soap in laundry. Low to moderate values of hardness have been reported in groundwater in Gboko and Katsina-Ala, Benue State and (Okoye & Nyietagher, 2009; Ogbane, Omeje, Jimoh, Alabi, & Yahaya, 2022) ^[22, 20].

Sulphate levels

The sulphate levels for all the water samples were far below the WHO permissible range of 200-400 mg/L. The average value sulphate in borehole water resources was estimated to be 10.56 mg/L which was slightly higher than the estimated average value of sulphate in shallow well water resources which was 10.37 mg/L. The major physiological effects resulting from the ingestion of large quantities of sulphate are catharsis, dehydration, and gastrointestinal irritation. Water containing magnesium sulphate at levels above 600 mg/L acts as a purgative in humans. The presence of sulphate in drinking water can also result in a noticeable bitter taste; the lowest taste threshold concentration for sulphate is approximately 250 mg/L, as the sodium salt. Sulphate may contribute to the corrosion of water-based distribution systems. Low values of sulphate have been reported in groundwater in Benue State (Edaba, 2023) ^[12].

Nitrates Levels

The concentration of nitrates for all samples of water analysed were below the WHO permissible level of 50 mg/L. The values ranged from 6.29 mg/L for SW5 to 22.38 mg/L for SW3 showing a wide range of values across the shallow well water resources compared to the range in borehole water resources which is 8.39 mg/L to 13.29 mg/L. The average value of nitrates in the two sources of water resources was 11.33 mg/L; same in value. Nitrates change to nitrite in the body, which reduces oxygen uptake by hemoglobin. Nitrate in drinking water has long been considered a health threat for its ability to induce methemoglobinemia ('blue-baby syndrome') especially in bottle-fed infants (Levine, 2023) ^[18] and this health outcome is the basis of the Environmental Protection Agency's maximum contaminant level. It is also responsible for cyanosis and asphyxia in infants under three (3) months. Groundwater that is not properly protected, underlying agricultural uses often has elevated nitrate levels due to runoff of nitrogen fertilizers. Intake of nitrate from drinking water and dietary sources may cause increased exposure to Nitroso compounds through endogenous nitrosation. Pregnant women who drink nitrate contaminated water may be at risk of having spontaneous abortions or giving births to infants with congenital malformations especially, of the central nervous system. High concentrations have also been cited as a risk factor in developing gastric and intestinal cancer. Low Nitrate values have been reported in groundwater in Gboko, Benue State (Omonona & Okogbue, 2021) ^[23]. Exposure to nitrates in drinking water at concentration levels below the maximum contaminant level of nitrate is not only associated with pancreatic cancer as thought but, pose a risk in pregnant women (Omonona & Okogbue, 2021) ^[23].

Chloride Levels

The chloride levels were far below the WHO permissible range of 200-250 mg/L in drinking water. For shallow wells, the range of values was 17.04 mg/L for SW1 to 68.10 mg/L for SW3 while the range of value for borehole water was 11.36 mg/L for BH2 to 29.94 mg/L for BH1. The least value for chlorides was 11.36 mg/L for BH2 while the highest value was 68.10 mg/L for SW3. The average value of shallow well water resources which is 30.07 mg/L was higher than the average value for borehole water resources which is 21.60 mg/L. There is no known evidence that chlorides constitute any human health hazard. For this reason, chlorides are generally limited to 250 mg/L in supplies intended for public use because beyond such concentration, they impart taste. However, when concentration of free chlorine in water after chlorination is above the guideline value of 250 mg/L, it could result in irritation of the esophagus, a burning sensation in the mouth and throat, and spontaneous vomiting (WHO, 2022) ^[27]. Low chloride values have been reported in groundwater in Benue State (Ohiaba, Idakwoji, Umar, David, Idenyi, Imarhiagbe & Egbunu, 2023) ^[21].

Iron (Fe) Levels

The concentration of iron was found to be relatively higher in shallow wells than in borehole water with the average value for borehole being 0.3346 mg/L and shallow wells 1.0141 mg/L where both were above the WHO limit of 0.30 mg/L. SW2 recorded the highest value of 2.5677 mg/L

while BH1 recorded the lowest value of 0.1223 mg/L. Elevated iron levels in water can lead to undesirable effects such as a metallic taste, staining of plumbing and laundry, and may promote the growth of iron bacteria, potentially leading to pipe clogging issues (WHO, 2022) ^[27]. The contamination of iron in water far above the permissible level can impart a metallic taste in the water. The presence of high iron levels in shallow wells can be attributed to natural sources, including rock and soil leaching, or anthropogenic activities such as corrosion from nearby metal structures and waste runoff (Kumar & Ghosh, 2019) ^[17]. Elevated levels of iron in groundwater have been reported in groundwater in Katsina-Ala, a neighboring town to Gboko in Benue State (Ogbane *et al.*, 2022) ^[20].

Manganese (Mn) Levels

Borehole samples do not show any detectable levels of manganese, while shallow wells show the concentrations of 0.0324 mg/L for SW1 and 0.0972 mg/L for SW2, with SW2 exceeding the WHO limit of 0.05 mg/L. Elevated manganese levels in drinking water can imparts water taste, stain plumbing fixtures, and, with prolonged exposure, may lead to neurological issues, particularly in children (WHO, 2022). Low to moderately high values of manganese have been reported in groundwater sources in Benue State (Tsor, Biam, Terver, Amon & Jombo, 2022) ^[25]. The elevated manganese levels in shallow wells might arise from natural sources such as soil and geological formations, as well as from fertilizers or other agricultural runoff (Ahmad, 2019) ^[1].

Lead (Pb) Levels

While lead was not detected in borehole water samples, it was detected in two shallow wells. SW1 recorded the lead concentrations of 0.0489 mg/L and SW2, 0.0936 mg/L. The concentration of lead in SW2 was above the WHO permissible level of 0.05 mg/L. The average value of lead for borehole was 0.000 mg/L and 0.0285 mg/L for shallow wells. Long time exposure to lead, even at low level (just above the WHO permissible level), is known to have severe health impacts, including neurotoxic effects, developmental delays in children, and cardiovascular issues in adults (USEPA, 2021) ^[26]. Other effects of consuming water extremely contaminated by lead are enzyme inhibition, kidney impairment, neurological disorders, tetratogenic effect, and carcinogenic effect (Edeonovo, 2010) ^[13]. Likely sources of lead contamination in shallow wells include corrosion of lead-containing materials washed into it, runoff from agricultural areas, or polluted soil and sediment or wells dug near dumpsites. Low values of lead have been reported in groundwater sources in Benue State (Tsor *et al.*, 2022) ^[25].

Calcium (Ca) Levels

Calcium concentrations in all water samples were well within the WHO limit of 200 mg/L, the values ranged from 1.3333 mg/L (BH1) to 66.0000 mg/L (SW2). The average value calculated was 5.2000 mg/L for BH and 19.8667 mg/L for SW. This shows that the concentration of calcium was higher in shallow well water than in borehole. Moderate concentrations of calcium have been reported in groundwater in Katsina-Ala, Benue State (Ogbane *et al.*, 2022) ^[20]. Calcium in drinking water is generally beneficial, contributing to good bone health; however, excessive levels

can contribute to water hardness, causing scaling in pipes and affecting water-processing appliances. The presence of calcium in water sources is often due to natural dissolution of calcium-bearing minerals in the soil (Okoye & Nyietagher, 2009) [22].

Magnesium (Mg) Levels

Magnesium levels ranged from 0.8454 mg/L for BH2 to 5.9179 mg/L for SW2 and all the values were within the WHO permissible level of 150 mg/L. The average value of magnesium in shallow well water which was 3.4712 mg/L was higher than the average value of magnesium in borehole water (2.7000 mg/L). Magnesium in drinking water is beneficial though, it can cause hardness of water. Moderate levels of magnesium have been reported in groundwater in Katsina-Ala, Benue State (Ogbane *et al.*, 2022) [20].

Sodium (Na) Levels

Sodium levels in both borehole and shallow well samples were below the WHO recommended limit of 250 mg/L. Borehole sodium levels range from 0.0447 mg/L to 0.9832 mg/L, while shallow wells show higher but still acceptable levels of 1.8816 mg/L to 4.4291 mg/L. The average value of sodium in shallow well water was 3.3176 mg/L which was higher than the average value of sodium in borehole water with a value of 1.1547 mg/L. Elevated sodium concentrations in drinking water could lead to potential health issues like hypertension by use of such water sources over time (WHO, 2023) [28]. Sodium in groundwater sources is commonly due to geological leaching (Aluko & Odusanya, 2021) [3]. Low values of sodium have been reported in groundwater sources in Benue State (Buba, Ujah & Ibrahim, 2021) [8].

Potassium (K) Levels

Potassium levels in both borehole and shallow well samples were below the WHO recommended limit of 50 mg/L. Potassium levels were generally low in borehole samples, with values ranging from 0.0773 mg/L to 4.4970 mg/L, while shallow well samples show higher potassium concentrations which ranged from 3.3727 mg/L to 21.0387 mg/L, both still within the permissible limit of 50 mg/L. The average value of potassium in shallow well water which was 10.7174 mg/L was higher than the average value of potassium in borehole water which was 1.0541 mg/L. Although potassium is usually non-toxic at these levels, high concentrations can pose a risk to individuals with kidney disorders (EPA, 2022) [14]. Sources of potassium in water may include natural mineral deposits or anthropogenic influences such as fertilizer application or wastewater discharge from agricultural operations (Chaudhary & Bhardwaj, 2020) [9]. Low values of potassium have been reported in groundwater sources in Benue State (Buba *et al.*, 2021) [8].

Total organic carbon (TOC)

All samples contain the total organic within the WHO permissible level of 1% except BH5 which the percentage composition was 1.20% and SW1 with a value of 1.01%. The average percentage value of TOC in borehole water was 0.82% which was higher than the average value of TOC in borehole water with a value of 0.78%. Presence of organic matter in water causes decay and their putrefaction causes odour and deprivation of oxygen in water (Nkurumah, 2011)

[19]. Moderate levels of total organic carbon has been reported in groundwater sources in Nigeria (Edeonovo, 2010) [13].

Coliform

The results for total coliform show that most of the water resources analyzed were within WHO permissible level of <1 MPN index/100 mL which is equivalent to 0 CFU/mL (Coliform Forming Unit per milliliter). Only the estimated values of total coliform in SW2 with a value of 2 MPN index/100 mL and faecal coliform in SW2 with a value of 1 MPN index/100 mL were above the WHO permissible level of <1 MPN index/100 mL. The presence of thermo tolerant/faecal coliform populations in the shallow well water SW2 samples is an indicator of poor sanitary conditions, lack of a proper well cover with the cover being in a poor condition, lack of a standing stage, broken well head, and unhygienic handling of solid wastes around the well might have led to contamination of the well with microbial organisms. Microorganisms like *Escherichia coli* (*E. coli*) which is the major thermotolerant coliforms or faecal coliforms should not be present in drinking water (Nkurumah, 2011) [19] as it poses health challenges of causing diarrhea. Moderate levels of coliform contamination have been reported in groundwater sources of Gboko locality (Akertyo *et al.*, 2024) [2] and Makurdi, all in Benue State (Ohiaba, Idakwoji, Umar, David, Idenyi, Imarhiagbe & Egbunu, 2023) [21].

Conclusion

The contamination of iron was above the WHO permissible level of 0.30 mg/L and covered seven (7) water resources, out of ten (10) water resources. Contamination of drinking water with iron does not pose much health risk as it only imparts a metallic taste on the water. The result of manganese shows that though it was detected in only three shallow wells, the value for SW2 recorded at 0.0972 mg/L was above the WHO permissible level of 0.05 mg/L and elevated manganese levels in drinking water can impart a metallic taste. Lead was detected only in two (2) shallow well water resources; SW1 with a value of 0.0489 mg/L and SW2 with a value of 0.0936 mg/L which is above the WHO permissible level of 0.05 mg/L. Prolong consumption of water from SW2 poses the risk of enzyme inhibition, kidney impairment, neurological disorders, teratogenic effect, and carcinogenic effect. The coliform analysis showed that only one (1) shallow well water resources which is SW2 was contaminated by coliform with a total coliform estimated value of 2 MPN index/100 mL and faecal/thermotolerant coliform value of 1 MPN index/100 mL. This shallow well water poses a risk and water from it should not be consumed by humans without boiling. In summary, SW2 poses a health risk as it is the only water source analysed that the contamination of Fe, Mn, Pb, total and faecal/thermotolerant coliforms are all above the WHO permissible levels. Generally, the quality of the water resources based on the analysed parameters was excellent. In conclusion, the quality of both the borehole water resources and the shallow well water resources analysed were generally excellent. The WQI for the borehole water (BH) and shallow well water (SW) were 32 and 48, meaning that the water quality were respectively excellent though, the quality of BH is classified as being better because the smaller the WQI value, the better the quality of water.

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