Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2024, 11(10):51-57

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Analysis of Borehole Water with Aesthetical Acceptability in Igbogene-Epie, Bayelsa State, Southern Nigeria for Domestic Purposes.

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Abstract Borehole water (BHW) quality should be assessed before consumption, as its contamination has huge concern with human well-being. Accordingly, the aim of the study was to assess the quality of BHW with aesthetically acceptability for domestic consumption. The study assessed the microbial and physico-chemical parameters of 11 borehole water samples collected from Igbogene-Epie Town, Bayelsa State, Nigeria. Two samples were collected from a single borehole (BH) [BH2a, treated; and BH2b, untreated]. The pH and major cations and anions (CA) were analysed. While pH value range from 6.34 to 6.95 with a mean value of 6.65 indicating a slightly acidic condition; the results of the CA were all below standard guidelines for drinking water. Escherichia Staphylococcus sp., Klebsiella sp., Escherichia coli sp., Enterobacter faccalis sp., Salmonella sp., Shigella sp., and Bacillus sp. bacteria were also analysed. Results show that among the 11 samples analysed, 5 samples contain no Pseudomonads, 5 samples contain no coliform bacteria (CB), 3 samples contain both the Pseudomonads and CB, while no bacteria was found in sample BH5. Furthermore, results of BH2a and BH2b reveal that the chlorine treatment administered on sample BH2a effectively removed CB (2.76×10^4) and also reduced the concentration of Pseudomonads from 2.05×10^4 to 6.2×10^3. Based on the results, the following recommendations were made: (a) BH5 should be monitored against possible sources of BHW contamination to avoid future contamination. Though water sample BH5 was free of the contaminants investigated, water should be analysed for other contaminants before drinking; (b) water from BH1, and BH3-BH10 should be treated adequately before consumption. Overall, every BHW elsewhere, irrespective of its aesthetic appearance should be examined 'fit' before use for domestic consumption.

Keywords borehole water, microbial quality, drinking water quality, coliform bacteria, physicochemical quality.

1. Introduction

Water is a vital component of everyday life. Therefore, accessibility to clean water is a worldwide keen desire. The global environmental outlook report of 2020 indicates that about 30% of the world's population lack access to safe drinking water (accessed 23.11.2022). The consumption of water worldwide increases daily due to increasing population and industrialization. However, most of the water resources continue to dwindle due to improper environmental management practices. Water supply and accessibility is among the goals of the Sustainable Development Goals (SDGs), and is aimed at safeguarding environment sustainability [1, 2]. Consequently, efforts have been intensified by various governments and/or organizations to ensure that her people have access to potable water. However, some localities in the developing countries are still experiencing shortage of municipal water supply.

It has been reported that groundwater (GW: borehole water) affords potable water to an estimated 1.5 billion people worldwide daily and has proved to be the most unwavering resource for meeting rural water demand in sub-Saharan Africa [3], which represents the world's prevalent and most important source of fresh potable water. As such, it is pertinent to note that GW quality has great concern with mankind and directly related to human. However, the general observation is that groundwater quality varies from place to place, sometimes due to seasonal variations, the types of soils, rocks and surfaces through which it moves [4]. Anthropogenic activities can also alter the natural composition of GW: borehole water through improper disposal of chemicals, or injection of wastes directly into ground. Pesticides, and fertilizers applied to grasses and crops can accumulate and migrate to the water table, thus affecting GW: borehole water quality [5]. However, in the absence of municipal water supply, people resort to GW: borehole water as an alternative source of water to meet their water demands. Thus, humans abstract groundwater resources through a borehole for industrial, agricultural, and domestic use.

In developing countries like Nigeria where there is insufficient municipal water supply, hence GW (borehole water) is considered as the major source of water supply for consumption. That is, people get water from the groundwater table through abstraction pumps (commonly known as borehole), which is later subjected to treatments before drinking; commercialized in sachets and in bottles. The study area- Igbogene-Epie Town, Yenagoa, Bayelsa State, was selected because fifteen (15) GW points are aesthetically acceptable for drinking purposes. Consequently, the water from these boreholes are used for domestic purposes including drinking, cooking, and bathing by most households in the area.

GW quality is essential to human well-being, agriculture (including fish farming), and industry. The quality of drinking water is significant globally as microbial and chemical parameters are crucial for human and the environment health. Advances in water supply system from source to consumer is related to improvements in human health. The incidence of drinking water related disease is usually determined by its microbiological and chemical parameters [6]. It is also evident that water borne diseases continue to be among the major health concerns globally. For instance, a study established that the high prevalence of diarrhea among children and infants can be traced to the use of unsafe water and unhygienic practices, and in developing countries, 80% of all diseases and over 30% of deaths are related to drinking water [7]. Therefore, this study hopes to (a) assess the microbial and physicochemical quality of 10 GW samples collected from the study area; (b) evaluate the effectiveness of treating borehole water with chlorine. To establish the later, two samples (1 treated, and the other untreated) were collected from a single BH location.

2. Materials and Method

Study Area

Igbogene is a community in Epie-Atissa clan in the Yenagoa Municipal Area Council, Bayelsa State, South-South region of Nigeria. The city is located on 6o 16'03" E longitude and 4o 55'18" N latitude. This study area was chosen because 15 boreholes in the area produce water that is tasteless, odourless, and does not change colour even for as long as been kept.

Sample Collection and Analysis

A total of eleven (11) borehole water (GW) samples were collected from ten (10) boreholes out of the fifteen (15) boreholes using clean 50cl plastic bottles. That is, two samples were collected from one borehole, whose water happens to be treated with chlorine. The reason was to assess the effect of treatment on the BH water quality. Prior to water sampling, the plastic bottles were rinsed 2 to 3 times with the sample water. Samples were then collected and labelled BH1 to BH10. Portable hydrogen concentration (pH) meter, electrical conductivity (EC), and temperature were used onsite to determine the pH, EC, and temperature. The samples were then taken to the laboratory same day for microbiological and physicochemical analysis.

3. Results and Discussion

Physicochemical Properties Analysis

The eleven (11) borehole water samples were analysed for fourteen physicochemical parameters such as total dissolved solids (TDS), total suspended solids (TSS), nitrate (NO_3-), chloride (Cl^-), sulfate (SO_4^{2-}), total alkalinity (TA), total hardness (TH), bicarbonate (HCO_3), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{2+}), potassium (K^+), iron (Fe^{3+}), and manganese (Mn). These parameters were analysed using standard techniques reported in [8]. Analysis was done in triplicate, and average taken. The results were compared with [9] permissible limits (PL) for drinking water. Only pH was within the PL, while the rest properties were below. As at the time of this research, there was no study on physicochemical properties quality analysis on BHW that is aesthetically acceptable for domestic consumption to compare the current findings with. The physiochemical properties results from the current study are all compared with [9] limits for drinking water. Figure 1a shows the results of EC, TDS, $N0_3$, and Cl- of the current study compared with [9] guide lines, and all properties are lower than the PL. The results of SO_4^{2-}, TH, Ca^{2+}, and Mg^{2+} of the current study are presented in Figure 1b. Their values are also less than the [9] PL. Similarly, Na, K, Fe, and Mn contents of this study are in Figure 1c. Again, results of the current study are below the PL of [9]. Overall, all the physicochemical properties of water under discussion (Table 3.1) are less than [9] PL for drinking water.

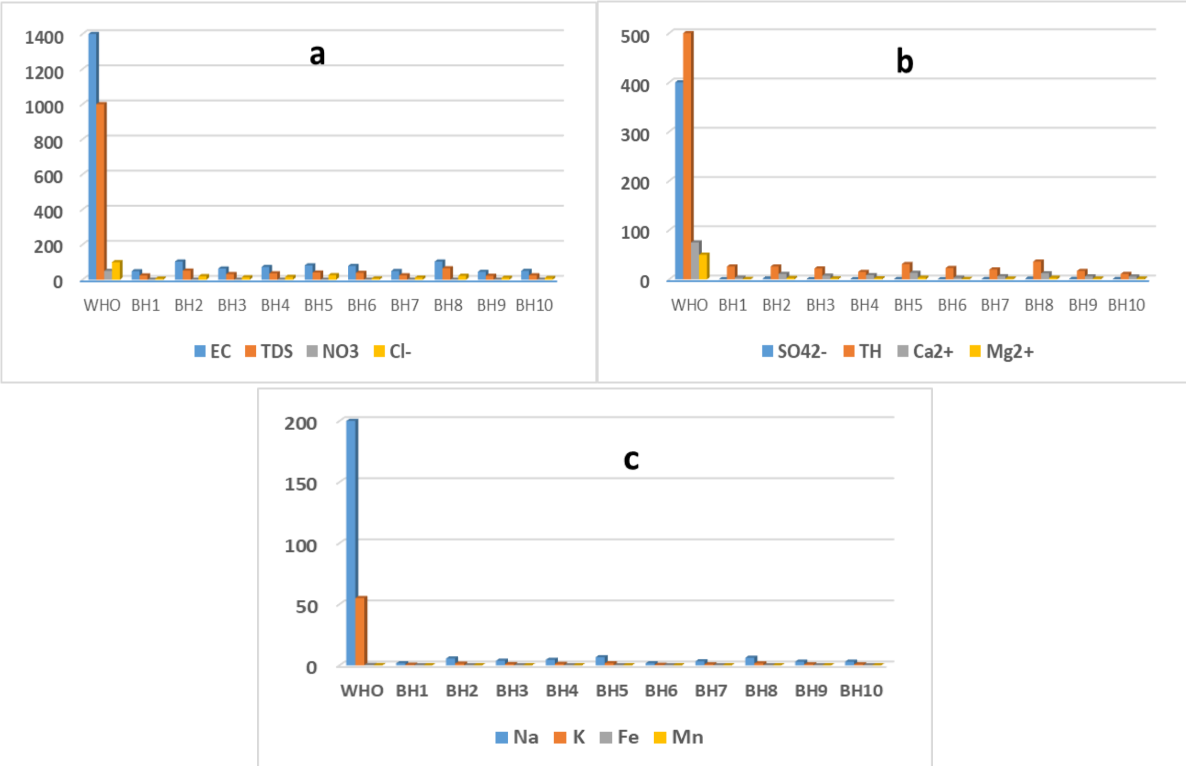

Figure 1: *Compares the contents of EC, TDS, $N0_3$, Cl- SO_4^{2-}, TH, Ca^{2+}, Mg^{2+} Na, K, Fe, and Mn in the current study and the guidelines of [9] for drinking water.*

Table 3.1: Physiochemical properties of borehole water samples compared with [9] permissible limit for drinking water.

Properties	**BH1**	**BH2**	**BH3**	**BH4**	**BH5**	**BH6**	**BH7**	**BH8**	**BH9**	**BH10**	**WHO, 2006 Max. PL**
pH	6.633	6.737	6.343	6.740	7.240	6.250	6.660	6.350	6.950	6.843	6.5-9.5
Salinity	0.02	0.04	0.01	0.03	0.03	0.01	0.02	0.06	0.01	0.02	na
EC	48.36	103.40	63.30	72.40	81.60	78.30	49.50	103.40	44.70	50.00	1400
TDS	24.20	51.75	31.80	36.30	40.80	39.15	24.75	65.20	22.35	25.00	1000
TSS	0.04	0.01	0.00	0.01	0.01	0.02	0.01	0.04	0.02	0.01	na
NO_3	0.046	0.054	0.018	0.026	0.037	0.110	0.105	0.125	0.110	0.113	50
Cl^-	6.00	20.00	14.0	16.0	26.00	7.0	12.0	22.00	11.00	10.00	100
SO_4^{2-}	0.34	1.54	0.40	0.32	0.64	0.40	0.51	1.38	0.75	0.65	400
HCO_3	0.00	0.60	0.60	0.70	0.81	0.00	0.20	1.00	0.50	0.70	na
TA	22.00	11.00	16.00	15.0	22.00	14.00	18.00	19.00	18.00	21.00	na
TH	26.00	26.00	22.0	15.0	31.00	23.00	20.00	36.00	17.00	11.00	500

C_a	3.33	11.10	7.46	8.56	13.24	3.26	6.36	12.24	6.15	5.75	75
M_g	0.83	2.77	1.87	2.16	3.31	0.82	1.60	3.20	1.54	1.44	50
N_a	1.67	5.55	3.73	4.51	6.62	1.63	3.25	6.13	3.00	3.00	200
K	0.42	1.40	0.94	1.13	1.66	0.40	0.80	1.53	0.72	0.72	55
F_e	0.012	0.01	0.025	0.015	0.020	0.032	0.010	0.066	0.020	0.020	0.3
M_n	0.00	0.001	0.001	-0.001	0.016	0.007	-0.002	0.013	0.013	0.013	0.1

Results presented in table 4.1 are summarized as follows:
1. The pH value ranges from 6.25 to 7.24 with an average of 6.65 indicating a slightly acidic condition.
2. The concentration of Fe^{3+} in the study area ranges from 0.01mg/l to 0.066mg/l with a mean value of 0.035mg/l.
3. The concentration of calcium Ca^{2+} ranges from 3.26mg/l to 13.241mg/l.
4. Magnesium Mg^{2+} concentrations range from 0.82mg/l to 3.31mg/l.
5. Electrical conductivity (EC) values range from 50mg/l to 103.4mg/l.
6. Total dissolved solids (TDS) values range from 22.35mg/l to 65.2mg/l.
7. Nitrate (NO_3) values range from 0.018mg/l t0o 0.125mg/l.
8. SO_4^{2-} values range from 0.32mg/l to 1.38mg/l.
9. TH values range from 11mg/l to 36mg/l.
10. K values range from 0.4mg/l to 1.66mg/l.
11. Na values range from 1.63mg/l to 6.62mg/l.

In comparison with WHO (2006) PL for drinking water, the values of all the parameters analysed are below WHO (2006) PL.

Microbial Quality Analysis

In terms of microbial quality, the samples were analyzed for Bacillus spp; Klebsiella spp; Salmonella spp; Staphlyloccus aureus; and Escherichia coli (E. coli). Also, heterotrophic and coliform bacteria, pseudomonads, faecal coliform bacteria, and biochemical test were carried out. Percentage of bacteria isolate was also determined. These bacteria were investigated because their presence in water is an indication potential risks to consumers. The microbial quality analysis in the current study followed the methods reported in Douglas et al. (2023). At the moment, there is no study yet on microbiological quality analysis on BHW with aesthetical acceptability for domestic consumption, which the current results can be compared with.

The bacteria isolation of study are presented in Table 3.2. Results show that Bacillus spp was the most isolated bacteria while Enterobacter faccalis Spp. was the least isolated. Other microorganisms isolated included Shigella spp., Escherichia coli, Staphylococcus spp, Salmonella spp and Enterobacter spp.

Table 3.2: The frequency and percentage of occurrence of bacteria isolate.

S/N	Bacteria isolate	Frequency of occurrence (FO)	Percentage of occurrence (PO)
1.	*Staphylococcus Spp.*	6	15.79
2.	*Klebsiella Spp.*	2	5.26
3.	*Esherichia coli Spp.*	7	18.42
4.	*Enterobacter faccalis Spp.*	1	2.63
5.	*Salmonella typhi Spp.*	7	18.42
6.	*Shigella Spp.*	7	18.42
7.	*Bacillus Spp.*	8	21.05
Total		**38**	**100**

Bacteriological analysis of water samples from eleven borehole was carried out. The results (mean) of the bacteriological analysis of the borehole water samples are as follows:

a) BH1: THB range from 4.3 to 7.1 × 10^3 with a mean value (MV) of 5.3 × 10^3; CB range from 1.2 to 2.5 × 10^4 with a mean MV of 1.99 × 10^4; and no Pseudomonads was found.

b) BH2a: THB range from 2.6 to 2.88 × 10^4 with a MV of 2.76 × 10^4; CB range from 2.27 to 2.5 × 10^4 with a MV of 2.07 × 10^4; Pseudomonads range from 1.99 to 2.16 × 10^4 with a MV of 2.05 × 10^4.

c) BH2b: THB range from 3.2 to 3.6 × 10^3 with a MV of 3.4 × 10^3; no CB was found; Pseudomonads range from 3.5 to 6.8 × 10^3 with a MV of 6.2 × 10^3. The absence of CD, and the lower count of Pseudomonads compared to its counterpart (i.e., BH2a) may be attributed to the treatment.
d) BH3: THB range from 2.73 to 3.0 × 10^4 with a MV of 2.9 × 10^4; CB range from 1.49 to 2.52 × 10^4 with a MV of 2.07 × 10^4; Pseudomonads range from 1.53 to 1.67 × 10^4 with a MV of 1.61 × 10^4.
e) BH4: THB range from 5.2 to 9.3 × 10^3 with a MV of 7.8 × 10^3; CB range from 1.48 to 1.52 × 10^4 with a MV of 1.0 × 10^4; and no Pseudomonads was found.
f) BH5: None of THB, CB and no Pseudomonads was found.
g) BH6: THB range from 2.72 to 3.0 × 10^4 with a MV of 2.98 × 10^4; no CB was observed; and Pseudomonads range from 3.1 to 3.6 × 10^3 with a MV of 3.3 × 10^3.
h) BH7: THB range from 3.0 to 3.3 × 10^3 with a MV of 3.1 × 10^3; no CB and Pseudomonads were found.
i) BH8: THB range from 2.4 to 2.68 × 10^4 with a MV of 2.52 × 10^4; CB range from 3.5 to 2.52 × 10^3 with a MV of 3.4 × 10^3; Pseudomonads range from 3.0 to 3.2 × 10^3 with a MV of 3.1 × 10^3.
j) BH9: THB range from 6.0 to 8.0 × 10^3 with a MV of 7.0 × 10^3; no CB and Pseudomonads were found.
k) BH10: THB range from 1.04 to 1.1 × 10^4 with a MV of 1.07 × 10^4; no CB was observed; Pseudomonads range from 1.9 to 2.4 × 10^4 with a MV of 2.14 × 10^4.
Table 3.3 shows the summary of results for the total heterotrophic bacteria count on nutrient agar for the different boreholes. The results indicate the population of heterotrophic bacteria in the borehole water sampled varied considerably. The total heterotrophic bacteria ranged from 2.76 × 10^3Cfu/ml in sample BH2a to 2.98 × 10^3Cfu/ml in sample BH6. The variations in the population of the heterotrophic bacteria provides an indication of the different sources and levels of contamination. However, we observed that there was no bacteria growth in sample BH5. The results for the enumeration of Pseudomonads are also presented in Table 3.3. The population of Pseudomonads ranged from 3.3 × 10^3 in sample BH6 to 2.14 × 10^3 in sample BH10; while no colonies were found in BH1, BH4, BH5, BH7, and BH9. Consequently, the presence of coliform bacteria in the groundwater samples makes the water unsafe for consumption.

Table 3.3: Mean values of total heterotrophic bacteria, coliform bacteria and pseudomonads in 10-borehole water samples. Analysis was done in triplicate.

	SAMPLE IDENTIFICATION										
BACTERIA (CFU/ml)	**BH1**	**BH2a**	**BH2b**	**BH3**	**BH4**	**BH5**	**BH6**	**BH7**	**BH8**	**BH9**	**BH10**
THB (10^3)	5.3	27.6	3.4	29.0	7.8	*	29.8	3.1	25.2	7.0	10.7
CB (10^3)	19.9	20.7	*	20.7	10.0	*	*	*	3.4	*	*
Pseudomonads (10^3)	*	20.5	6.2	16.1	*	*	3.3	*	31	*	21.4

THB = Total Heterotrophic Bacteria; **CB** = Coliform Bacteria; **BH** = Borehole; and * = no colony

The results for the enumeration of coliform bacteria is shown in Table 3.4. The coliform bacteria ranged from 3.4 × 10^3Cfu/ml in BHI to 2.07 × 10^3Cfu/ml in sample BH2a and BH3 respectively. However, no coliform growth was recorded in samples BH2b, BH5, BH6, BH9 and BH10 respectively. Consequently, the presence of coliform bacteria in the groundwater samples makes the water unsafe for consumption.

Table 3.4: Estimation of faecal coliform bacteria using most probable number (MPN)

Sample volume:	**50ml**	**10ml**	**1ml**	
Sample bottles:	**1**	**5**	**5**	**MPN/50ml**
BH1	**1**	**2**	**3**	**12**
BH2a	**1**	**3**	**3**	**18**
BH2b	**0**	**1**	**0**	**1**
BH3	**1**	**2**	**2**	**10**
BH4	**1**	**3**	**1**	**11**
BH5	**0**	**0**	**0**	**0**
BH6	**0**	**0**	**2**	**2**
BH7	**0**	**2**	**1**	**3**
BH8	**1**	**0**	**3**	**6**
BH9	**0**	**1**	**2**	**3**

BH10	**0**	**1**	**0**	**1**

Table 3.5: Morphological characterization and biochemical test results of the water samples analyzed

Gr	Oxi	Cit	Ind	Cat	Glu	Lac	Gas	H_2g	FO	PO	Bacteria isolates
Positive cocci	-	+	-	+	+	+	-	-	6	15.79	*Staphylococcus Sp.*
Negative rod	-	+	-	+	+	+	+	-	2	5.26	*Klebsiella Sp.*
Negative rod	-	-	+	+	+	+	+	-	7	18.42	*Escherichia Sp.*
Positive coccus	-	-	-	+	+	+	-	-	1	2.63	*Enterobacter Sp.*
Negative rod	-	-	-	+	+	-	+	+	7	18.42	*Salmonella Sp.*
Negative rod	-	-	+	+	+	-	-	-	7	18.42	*Shigella Sp.*
Positive rod	-	+	-	+	+	+	-	-	8	21.05	*Bacillus Sp.*

Gr = gram reaction, **Oxi** = oxidase, **Cit** = citrate, **Ind** = indole test, **Cat** = catalase, **Glu** = glucose, **Lac** = lactose,
FO = frequency of occurrence, **PO** = percentage of occurrence, + = indicates presence of bacteria, and **-** = absence of bacteria.

Morphological characterization and biochemical tests were carried out. Results showed seven isolates: Staphylococcus Sp.; Klebsiella Sp.; Escherichia Sp.; Enterobacter Sp.; Salmonella Sp.; Shigella Sp.; and Bacillus Sp in the untreated water sample, whereas none was identified in the treated samples. The results are presented in Table 3.5. The presence of the microbes in water samples indicate fecal contamination. Their presence might be due to infiltration of microbes from sources like septic tanks that are close to the borehole or which flows in the direction of the borehole. The frequency of occurrence varies from 1 to 8; with 7 dominating. The percentage of occurrence varies from 2.63 to 18.42; with 18.42 dominating. In both cases (i.e., FO and PO), Escherichia Sp., Salmonella Sp. and Shigella Sp are leading.

4. Conclusions

This study was carried out to evaluate the quality of borehole water with aesthetically acceptability for domestic purposes. All the physicochemical parameters analyzed were within the standards set by WHO for water. However, coliform bacteria were present in the water samples analyzed. The presence of potential pathogenic bacteria such as Enterobacter Sp., Escherichia Sp., Salmonella Sp. and Shigella Sp show that the water is unsafe for domestic purposes. Consequently, results suggest that:

1. not all borehole waters are safe for consumption. Therefore, to prevent the outbreak of waterborne illnesses borehole water should be properly treated to ensure it is safe for use.
2. At domestic level, add chlorine followed by boiling before drinking while commercially reverse osmosis, aeration and novel methods such as the use of ultrasound with frequencies above 20kHz can be applied to disinfect the water.
3. The people in the study area should be enlightened on the microbial quality because ordinarily the water appears to be clean but it is not fit for drinking.

In conclusion, every borehole water elsewhere, irrespective of its aesthetic appearance should be examined ‘fit’ before use for domestic consumption.

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