

Assessment of Groundwater Quality in Rumuodara, Rivers State, Nigeria

Love Wilcox Arimieari^{1,*}, Benedict Emeka Omenogor²

Abstract

The assessment of groundwater quality from selected borehole in Rumuodara, Rivers State, Nigeria was evaluated. The results of the physicochemical parameters revealed that pH ranged from 6.57-6.60, temperature: 26.10-28.54°C, turbidity: 1.57-2.96NTU, conductivity: 41.24-68.44 $\mu\text{S/cm}$, salinity: 26.10-50.37mg/l, total dissolved solid: 18.9-63.14mg/l, total hardness: 38.21-48.30mg/l, alkalinity: 55.30-70.17mg/l, chloride: 28.40-75.14mg/l, sulphate: 21.50-30.60mg/l, nitrate: 1.50-3.04mg/l, phosphate: 59.24-65.40mg/l, calcium: 37.81-45.27mg/l, Iron: 0.133-0.190mg/l, sodium: 16.70-21.13mg/l, copper: 0.22-0.50mg/l, total suspended solid: 2.94-3.60mg/l, Lead: < 0.01mg/l-2.27mg/l, zinc: 1.16-2.40mg/l, Colour: 2.4-5.18Hazen, dissolved oxygen: 3.90-6.40mg/l, reactive silica: 3.64-4.52mg/l, and bicarbonate: 40.06-51.90mg/l. Microbiological analysis of the borehole water samples revealed that the total heterotrophic bacteria count ranged from 3.8-28.1 cfu/100ml and total coliform count ranged from 0.9-7.5 cfu/100ml. The investigation of this study attests that, the physicochemical parameters of the borehole water samples were below the WHO and NSDWQ permissible limits, with the exception of lead (2.27mg/l) which was found in borehole water in Chukwuodara. Also, the results of the microbiological analysis obtained from the borehole water samples showed that all borehole water samples conformed to the WHO and NSDWQ limit of 0 cfu/100ml for fecal coliform. Nevertheless, the borehole water samples contained total coliform and total heterotrophic bacteria (THB) above the WHO permissible limit of 0 cfu/100ml for total coliform and 1 cfu/100ml for total heterotrophic bacteria, but below the NSDWQ permissible limit of 10 cfu/100ml for total coliform. The overall suitability of the borehole water samples for drinking was accessed with the water quality index (WQI) using NSDWQ/WHO standard. The WQI of borehole water samples in Mgbuesilaru, Eliowhani and Chukwuodara were 9 (excellent water quality), 26 (good water quality) and 18,722 (unsuitable for drinking). Thus, the counts of THB (28.1 cfu/100ml) and the concentration of lead (2.27mg/l) reduced the quality of drinking water sourced from the selected borehole in Eliowhani and Chukwuodara. This study recommends that groundwater quality should be assessed prior to consumption, to ascertain drinking water safety.

Keywords: Groundwater Quality, Assessment, Water Quality Index, Rumuodara, Rivers State, Nigeria

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INTRODUCTION

Groundwater is the water beneath the earth's surface where all the voids in the rocks and soil are filled. It is a source of water for wells, boreholes and springs. Groundwater plays a vital role as an important source of potable water in both rural and urban areas, and thus plays a vital role in the water supply chain [1]. Therefore access to good quality water is a necessity and the availability of water in the desired quantity and quality, has been the key to the survival of all civilizations. A major portion of the earth's water circulatory system comprises of groundwater known as hydrological cycle and occurs in a permeable geological formation known

as aquifers [2]. Groundwater is of greater importance than surface water source because it is the largest reserve of drinkable water in regions where humans can live [3].

More so, groundwater from boreholes and shallow wells are a major source of drinking water in most rural areas of developing countries of the world [4]. Nevertheless, the availability of quantitative and qualitative water supplies for humans have over the years, influenced the settlement patterns of people in certain geographical regions in preference to others [3]. A borehole is a hydraulic structure which when properly designed and constructed, permits the economic withdrawal of water from an aquifer; it is a narrow well drilled with a machine [5]. Thus, the use of borehole is a simple way of obtaining water from the aquifer below the ground, after which the water can be pumped into a storage tank [6]. The distance between the site of the borehole and a septic/soak-away tank, distance between the borehole and a refuse dump unit, depth of the borehole and the distance between the borehole and a neighbor's septic tank are all factors to be solely considered prior to drilling a borehole due to limited plot allocation [7].

Borehole water serves as the major source of drinking water in the local population of Nigeria, since only very few can afford and rely on purified and treated bottled water for consumption [8]. However, the purity of drinking water from boreholes remains questionable [9]. Although water is one of the most essential components of life, it is not accessible to a large number of populations in the recommended quality [10]. In Nigeria today, one of the most important environmental issues is groundwater contamination [11]. Therefore, despite the need to ensure sufficient water quantity, one of the biggest development challenges is ensuring sufficient water quality [12]. Hence the subject of safe drinking water is important topic in the world [13]. Water quality refers to the chemical, physical and biological characteristics of water, which is determined by the presence of both organic and inorganic compounds that are either suspended or dissolved in it. It is also a measure of the condition of water relative to the requirements of one or more biotic species and any human need or purpose [14]. Ground water depth and quality varies from place to place and this affects the quality of water obtained. Water moving through underground rocks and soils may pick up natural contaminants, even with no human activity or pollution in the area [15]. However, the shallow water table conditions typical of the Niger Delta, makes it easy for contaminants to percolate downward, to the shallow water table resulting in contamination of groundwater [16].

Water should be free from any physical, chemical or bacteriological contaminant, but unfortunately water is not always found pure. It is for such reason that drinking water quality standards are set up to ensure the safety of drinking water supplies and the protection of public health [17].

On a global scale, the World Health Organization (WHO) set safe limits of contaminants that are used as the basis for regulation and standard setting, in developing and developed countries world-wide.

The most effective method for measuring water quality with reference to drinking water standards is the Water Quality Index (WQI). The water quality index approach uses a number of water quality parameters in a mathematical equation, to rate water quality, determining the suitability of the water for drinking [18]. It simplifies numerous water quality data into a single-value output that is easily interpretable, even by lay people [19].

Hence it is very important to judge the safety of water with respect to its physical, chemical and bacteriological properties before it can be exploited for human consumption. This is however not always the case in many developing countries, sometimes due to financial and poor quality control issues [20].

MATERIALS AND METHODS

Study Area

The study was conducted in Rumuodara (4.8634°N, 7.0322°E) situated in Obio-Akpor Local Government Area, Port Harcourt, Rivers State, Nigeria. Port Harcourt is located within the Niger Delta Basin of Southern Nigeria, within the eastern lower Niger Delta in the south eastern part of Rivers State

of Nigeria. It is situated at the right bank of the Bonny River approximately 65km inland from the Bight of Bonny.

Borehole Water Sampling

Representative samples of borehole water were obtained from selected boreholes in the study area, which were: Mgbesilaru, Eliowhani, and Chukwuodara. Cotton wool soaked in 70% ethanol was used to sterilize the nozzle of the tap, of the storage tanks from which borehole water samples were collected. The tap was allowed to run for two minutes before sterile screw capped plastic bottle was carefully uncapped and filled with water and recapped. As part of quality control measures, all bottles were rinsed with de-ionized water to minimize any chance of contamination, followed by three times with the borehole water to be sampled. Each bottle was labeled according to the sampling location to avoid mixing error and was taken to the laboratory in coolers of ice for analysis within 24 hours. The sample identification code for each sample location is tabulated in Table 1.

Table 1. Sample Code of Selected Boreholes with Their Respective Location.

Sample Code of Selected Borehole	Sample location
BH1	Mgbuesilaru
BH2	Eliowhani
BH3	Chukwuodara

Borehole Water Sample Analysis

The adopted methods of analyses for the examination of all parameters in the borehole water samples were in accordance with the procedure recommended in standard methods for the examination of water and wastewater [21]. All samples were analyzed for selected physicochemical and microbiological parameters.

Method of Data Analysis

Water Quality Index (WQI) for each sample was calculated using the Weighted Arithmetic Mean method as described by [22, 23]. In determining water quality index, the parameters used for the indices of water quality in this study were carefully selected to accurately reflect the major acceptability and health issues relating to water quality. Nineteen parameters were selected using NSDWQ/WHO standard as shown in Table 2.

Table 2. Water Quality Parameters with NSDWQ/WHO Standard and Unit Weights.

N	Parameter (P _i)	Standard (S _i)	Unit weight (W _i)
1	Aluminum (mg/l)	0.2	0.0412
2	Hardness (mg/l)	150	0.0000549
3	Conductivity (μS/cm)	100	0.0000824
4	Chloride (mg/l)	250	0.0000329
5	Colour (Hazen)	15	0.000549
6	Copper (mg/l)	1	0.00824
7	Iron (mg/l)	0.3	0.0274
8	Manganese (mg/l)	0.2	0.0824
9	Nitrate (mg/l)	50	0.000824
10	pH	8	0.00103
11	Sodium (mg/l)	200	0.0000412
12	Sulphate (mg/l)	100	0.0000824
13	Alkalinity	400	0.0000206
14	Turbidity (NTU)	5	0.00164
15	Total dissolved solid (mg/l)	500	0.0000164
16	Lead (mg/l)	0.01	0.824
17	Total coliform (cfu/100ml)	10	0.000824
18	Total heterotrophic bacteria (cfu/100ml)	1	0.00824
19	Zinc (mg/l)	3	0.0164

The Unit weight of the *i*th parameter (W_{*i*}) was calculated as follows:

$$W_i = \frac{k}{s_i}$$

Where,

K = proportionality constant, and was calculated by using the following equation:

$$K = \frac{1}{\sum \left(\frac{1}{s_i} \right)}$$

The quality rating scale (Q_i) for each parameter was calculated by using the expression:

$$Q_i = 100 \frac{v_i - v_o}{s_i - v_o}$$

Where,

V_i = Estimated concentration of the i^{th} parameter of interest in the analyzed water.

V_o = The ideal value of the i^{th} parameter in pure water. $V_o = 0$ (except pH = 7.0; and DO = 14.6mg/l)

S_i = Recommended Standard value of the i^{th} parameter

Finally, the water quality index (WQI) was computed by finding the weighted arithmetic mean of the quality rating (Q_i)

$$WQI = \frac{\sum Q_i W_i}{\sum W_i}$$

Where i is from 1 to 10 for both summation

Table 3. Water Quality Rating As Per Weighted Arithmetic Mean Method.

WQI Value	Rating of Water Quality	Grading
0 – 25	Excellent water quality	A
26 – 50	Good water quality	B
51- 75	Poor water quality	C
76 – 100	Very poor water quality	D
Above 100	Unsuitable for drinking purpose	E

Source: [23]

RESULTS AND DISCUSSION

The result of the physicochemical properties of borehole water samples sourced from selected boreholes in Rumuodara are presented in Tables 3 and 4 while microbiological properties of borehole water samples from Rumuodara are shown in Table 5. The computation of sub index for BH 1 (Mgbesilaru), BH 2 (Eliowhani) and BH3 (Chukwuodara) are presented in Tables 6 – 8 respectively. The computation of water quality index for borehole water samples are shown in Table 9.

Table 4. Physicochemical Properties of Borehole Water Samples from Rumuodara.

N	PARAMETER	BH1	BH2	BH3	WHO	NSDWQ
1	pH	6.59	6.57	6.60	6.5-8.5	6.2-8.5
2	Temperature (°C)	26.10	28.0	28.54	NA	Ambient
3	Turbidity (NTU)	1.57	2.96	2.50	5	5
4	Conductivity (µS/cm)	68.44	41.24	50.20	<100	1000
5	Salinity (mg/l)	50.37	26.10	35.66	400	NA
6	Total Dissolved Solid (mg/l)	27.41	18.96	63.14	500	500
7	Total Hardness as CaCO ₃ (mg/l)	41.33	48.30	38.21	150	150
8	Alkalinity (mg/l)	70.17	59.97	55.30	400	NA
9	Chloride (mg/l)	35.19	75.14	28.40	250	250
10	Sulphate (mg/l)	27.12	21.50	30.60	400	100
11	Nitrate (mg/l)	1.80	1.50	3.04	45	50
12	Phosphate (mg/l)	65.40	60.93	59.24	<100	NA
13	Manganese (mg/l)	<0.01	<0.01	<0.01	0.10	0.2
14	Calcium (mg/l)	37.81	42.19	45.27	75.0	NA
15	Magnesium (mg/l)	<0.01	<0.01	<0.01	0.10	0.20

16	Iron (mg/l)	0.190	0.133	0.144	0-0.3	0.3
17	Aluminum (mg/l)	<0.01	<0.01	<0.01	0.2	0.2
18	Sodium (mg/l)	18.52	21.13	16.70	<200	200
19	Copper (mg/l)	0.22	0.35	0.50	<3.0	1
20	Total Suspended Solid (mg/l)	3.60	3.14	2.94	2-5	NA
21	Lead (mg/l)	<0.01	<0.01	2.27	0.05	0.01
22	Zinc (mg/l)	2.40	1.16	2.18	5.0	3
23	Odour	UN	UN	UN	UN	UN
24	Colour (Hazen)	2.40	3.38	5.18	15.00	15.00
25	Dissolved Oxygen (mg/l)	6.34	6.40	3.90	7.0	NA
26	Ammonia (mg/l)	<0.01	<0.01	<0.01	0.1	NA
27	Reactive Silica (mg/l)	4.52	3.64	4.19	40.0	NA
28	Dissolved carbon dioxide (mg/l)	Nil	Nil	Nil	Nil	Nil
29	Appearance	Clear	Clear	Clear	Clear	Clear
30	Taste	UN	UN	UN	UN	UN
31	Bicarbonate	40.06	51.90	48.16	<1000	NA

BH1-BH3 = Sample location in the study area, NA- Not available, UN- Unobjectionable, NTU-Nephelometric turbidity unit

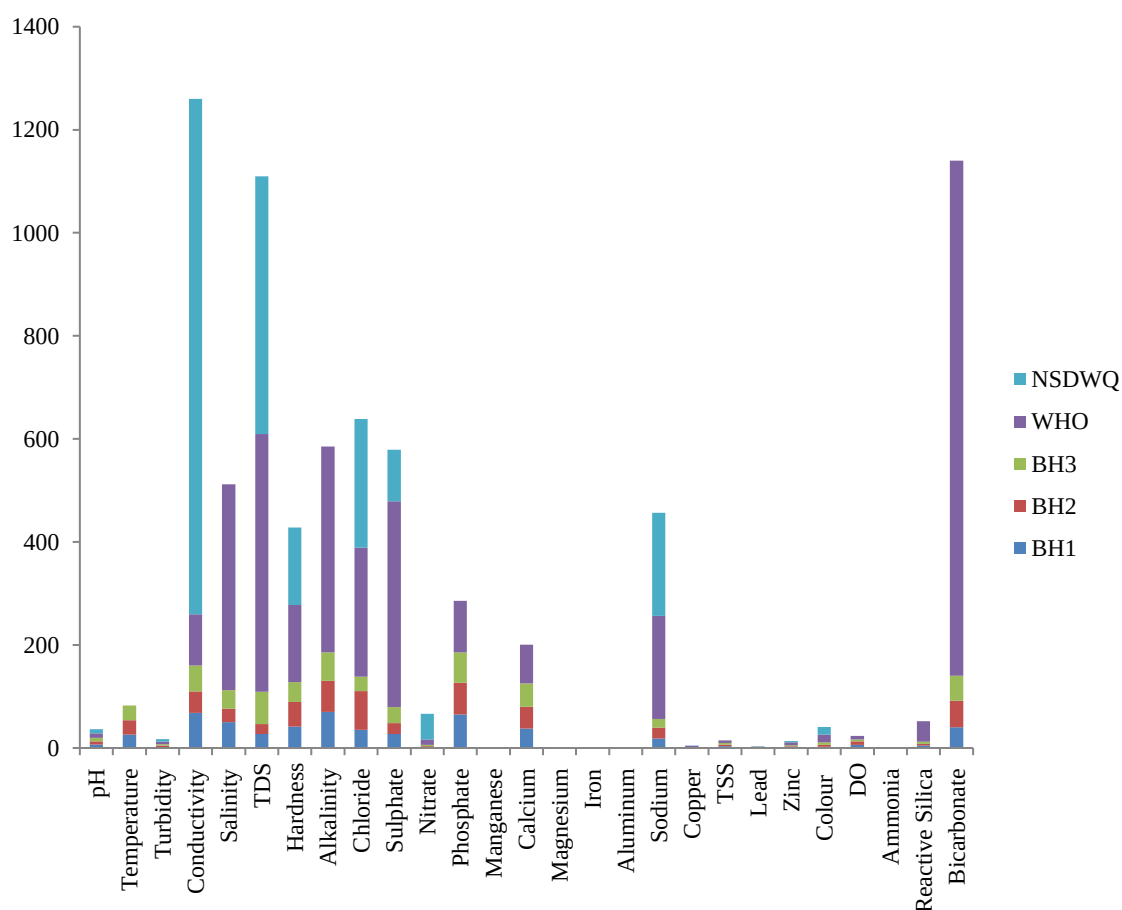


Figure 1. Analytical Values of Physicochemical Parameters for Borehole Water Samples with WHO and NSDWQ Limit.

Table 5. Microbiological Properties of Borehole Water Samples from Rumuodara.

N	PARAMETER	BH1	BH2	BH3	WHO	NSDWQ
1	Total heterotrophic bacteria (cfu/100ml)	7.0	28.1	3.8	1	NA
2	Total coliform counts (cfu/100ml)	7.5	0.9	3.7	0	10
3	Feacal coliform counts (cfu/100ml)	Nil	Nil	Nil	0	0

BH1-BH3= Sample location in the study area, NA- Not available

Table 6. Computation of Sub Index for BH 1 (Mgbesilaru).

N	Parameter (P _i)	Observed value (V _i)	Quality (Q _i)	Sub index (Q _i W _i)
1	Aluminum (mg/l)	0.009	0.045	0.18548
2	Hardness (mg/l)	41.33	0.27553	0.00151
3	Conductivity (μS/cm)	68.44	0.6844	0.00564
4	Chloride (mg/l)	35.19	0.14076	0.0004641
5	Colour (Hazen)	2.4	0.16	0.0087933
6	Copper (mg/l)	0.22	0.22	0.1813632
7	Iron (mg/l)	0.19	0.63333	1.7403546
8	Manganese (mg/l)	0.009	0.09	0.7419406
9	Nitrate (mg/l)	1.8	0.18	0.0148388
10	pH	6.59	1.41	0.1452967
11	Sodium (mg/l)	18.52	0.0926	0.0003816
12	Sulphate (mg/l)	27.12	0.2712	0.0022357
13	Alkalinity	70.17	0.175425	0.0003615
14	Turbidity (NTU)	1.57	0.314	0.0517709
15	Total dissolved solid (mg/l)	27.41	0.05482	9.03849E-05
16	Lead (mg/l)	0	0	0
17	Total coliform (cfu/100ml)	7.5	0.75	0.061828
18	Total heterotrophic bacteria (cfu/100ml)	7	7	5.770649
19	Zinc (mg/l)	2.4	0.8	0.219834

Table 7. Computation of Sub Index for BH 2 (Eliowhani).

N	Parameter (P _i)	Observed value (V _i)	Quality (Q _i)	Sub index (Q _i W _i)
1	Aluminum (mg/l)	0.009	0.045	0.185485
2	Hardness (mg/l)	48.3	0.322	0.001769
3	Conductivity (μS/cm)	41.24	0.4124	0.003399
4	Chloride (mg/l)	75.14	0.30056	0.00099
5	Colour (Hazen)	3.38	0.22533	0.012383
6	Copper (mg/l)	0.35	0.35	0.288532
7	Iron (mg/l)	0.133	0.44333	1.218248
8	Manganese (mg/l)	0.009	0.09	0.741940
9	Nitrate (mg/l)	1.5	0.15	0.012365
10	pH	6.57	1.43	0.1473576
11	Sodium (mg/l)	21.13	0.10565	0.000435
12	Sulphate (mg/l)	21.5	0.215	0.001772
13	Alkalinity	59.97	0.149925	0.000308
14	Turbidity (NTU)	2.96	0.592	0.097606
15	Total dissolved solid (mg/l)	18.96	0.03792	6.25209E-05
16	Lead (mg/l)	0	0	0
17	Total coliform (cfu/100ml)	0.9	0.09	0.007419
18	Total heterotrophic bacteria (cfu/100ml)	28	28	23.08259
19	Zinc (mg/l)	1.16	0.38666	0.106253

Table 8. Computation of Sub Index for BH3 (Chukwuodara).

N	Parameter (P _i)	Observed value (V _i)	Quality (Q _i)	Sub index (Q _i W _i)
1	Aluminum (mg/l)	0.009	0.045	0.18548
2	Hardness (mg/l)	38.21	0.25473	0.00139
3	Conductivity (μS/cm)	50.2	0.502	0.00413
4	Chloride (mg/l)	28.4	0.1136	0.000374
5	Colour (Hazen)	5.18	0.34533	0.0189790
6	Copper (mg/l)	0.5	0.5	0.412189
7	Iron (mg/l)	0.144	0.48	1.319005
8	Manganese (mg/l)	0.009	0.09	0.74194
9	Nitrate (mg/l)	3.04	0.304	0.025061
10	pH	6.6	1.4	0.144266
11	Sodium (mg/l)	16.7	0.0835	0.000344
12	Sulphate (mg/l)	30.6	0.306	0.002522
13	Alkalinity	55.3	0.13825	0.000284
14	Turbidity (NTU)	2.5	0.5	0.082437
15	Total dissolved solid (mg/l)	63.14	0.12628	0.000208
16	Lead (mg/l)	2.27	227	18713.39
17	Total coliform (cfu/100ml)	3.7	0.37	0.030502
18	Total heterotrophic bacteria (cfu/100ml)	3.8	3.8	3.132638
19	Zinc (mg/l)	2.18	0.72666	0.199682

Table 9. Computation of Water Quality Index for Borehole Water Samples.

Sanmple code	$\sum Q_i W_i$	$\sum W_i$	WQI	Grade	Remark
BH 1	9.1328	0.99958	9	A	Excellent water quality
BH 2	25.9089	0.99958	26	B	Good water quality
BH 3	18719.69	0.99958	18722	E	Unsuitable for drinking purpose

Water Quality Index of Borehole Water Samples from Rumuodara

The application of water quality index (WQI) in this study has been profoundly useful in the assessment of the overall quality of borehole water. The water quality parameters that mostly influenced the WQI outcome were lead and total heterotrophic bacteria (THB). This was due to their low permissible standard along with the concentration of lead and the counts of THB that surpassed the permissible standard.

Furthermore, an excellent water quality was obtained only in the selected borehole in Mgbuesilaru. The water was considered excellent mainly due to the low chemical and bacteriological parameter values, contributing to lower composite effect on drinking water quality. In the selected borehole in Eliowhani, the borehole water was classified as good water quality. Thus, the count of total heterotrophic bacteria found in the borehole water reduced its quality. More so, in the selected borehole in Chukwuodara, the high level of lead found in the borehole water rendered it unsuitable for drinking as depicted by the water quality index.

However, the water sourced from the selected borehole in Mgbuesilaru rated a better quality to that sourced from the selected borehole in Eliowhani and Chukwuodara. Comparing the water quality of the water sourced from the selected borehole in Eliowhani and Chukwuodara, Eliowhani had a better water quality than Chukwuodara, based on the water quality index.

Physicochemical Properties of Borehole Water Samples from Rumuodara

The pH values obtained from laboratory analysis were 6.59, 6.57 and 6.60 for BH1, BH2 and BH3 respectively. This is an indication of weak acidity. However the observed pH values for the borehole water samples were within the acceptable limits for drinking water quality as recommended by NSDWQ and WHO.

The temperature values for the borehole water samples were 26.10°C, 28.0°C and 28.54°C for BH1, BH2 and BH3 respectively. Temperature values are known to be dependent on the climatic condition at a particular geographical area and period.

The level of turbidity in drinking water is important for aesthetic reasons. It has no direct health effects; however, it can interfere with disinfection and provide a medium for microbial growth [24]. In this study, the turbidity values for the borehole water samples were 1.57 NTU, 2.96 NTU and 2.50 NTU for BH1, BH2 and BH3 respectively. However all borehole water samples had turbidity values below the NSDWQ and WHO guideline value of 5 NTU.

The conductivity values for BH1, BH2 and BH3 were 68.44µs/cm, 41.24µs/cm and 50.20µs/cm. These results are below the WHO and NSDWQ permissible limit of 100µS/cm and 1000µS/cm for conductivity.

The salinity levels recorded in the study area were 50.37mg/l, 26.10mg/l and 35.66mg/l for BH1, BH2 and BH3 respectively. This is as a result of the location of the area, far away from the coast. However the salinity levels recorded were below the WHO permissible limit of 400mg/l.

High concentration of total dissolved solids (TDS) can give water a bitter, metallic or salty taste, along with discoloring water and an unpleasant odour. More so, high concentration of TDS may affect persons who are suffering from kidney and heart diseases [25]. The concentration of TDS found in

borehole water samples were 27.41 mg/l, 18.96mg/l and 63.14mg/l for BH1, BH2 and BH3 respectively. These values are below the NSDWQ and WHO recommended standard of 500mg/l.

The concentration of hardness for borehole water samples were 41.33mg/l, 48.30mg/l and 38.21mg/l for BH1, BH2 and BH3 respectively. These concentrations are below the NSDWQ and WHO recommended standard of 150mg/l. Very hard water is not good for drinking and is associated with rheumatic pains and goiter [26], [27].

Excessive alkalinity may cause stomach upset, encrustation of utensils and pipes. More so, alkaline waters may also have a distinctly flat and unpleasant taste. In this study the alkalinity concentrations in borehole water samples were found to be 70.17 mg/l, 59.97 mg/l and 55.30mg/l for BH1, BH2 and BH3 respectively. These values are below the WHO acceptable limit of 400 mg/l.

Chloride ions are among the most important anions in water as they help maintain acid-base balances nevertheless, excess of it may cause edema [28]. However, concentration of chloride above 250 mg/l may result in objectionable taste of water to consumers. In this study, the concentration of chloride obtained from the borehole water samples were 35.19mg/l, 75.14mg/l and 28.40mg/l for BH1, BH2 and BH3 respectively. These values are below the NSDWQ and WHO permissible standard of 250mg/l.

The concentration of sulphate found in the borehole water samples were 27.12mg/l, 21.50mg/l and 30.60mg/l for BH1, BH2 and BH3 respectively. The observed concentrations are below the WHO recommended limit of 400mg/l and NSDWQ limit of 100mg/l. While sulphate imparts a slightly milder taste to drinking water than chloride, no significant taste effects are detected below 300 mg/l [29].

Water that is contaminated with nitrate proves harmful especially to infants causing methaemoglobinaemia otherwise called infantile cyanosis or blue baby syndrome if consumed [30]. The concentrations of nitrate found in the borehole water samples were 1.80 mg/l, 1.50 mg/l and 3.04 mg/l for BH1, BH2 and BH3 respectively. These values are well below the WHO and NSDWQ permissible limits of 10mg/l and 50mg/l respectively. Thus, the concentration of nitrate in the borehole water samples does not pose any health risk to water users.

High concentrations of phosphate in drinking water may lead to digestive problems. However, the concentration of phosphate in the borehole water samples was 27.12mg/l, 21.50mg/l, and 30.60mg/l for BH1, BH2 and BH3 respectively. These values are well below the WHO permissible limit of 400mg/l and the NSDWQ permissible limit of 100mg/l.

A concentration of manganese above 0.20mg/l can result in neurological disorder [31]. However, the concentration of manganese for all borehole water samples were below 0.01mg/l, which is below the WHO permissible limit of 0.10mg/l and NSDWQ limit of 0.2 mg/l. Calcium and magnesium are predominant minerals in groundwater [32]. Calcium is essential for the formation of bones however excessive calcium in drinking water may contribute to the formation of kidney and bladder stones. The concentration of calcium found in the borehole water samples were 37.81mg/l, 42.19mg/l and 45.27mg/l for BH1, BH2 and BH3 respectively. These values are well below the WHO recommended limit of 75mg/l.

In this study, the concentration of magnesium in the borehole water samples were below 0.01mg/l, which is below the WHO permissible limit of 0.10mg/l and NSDWQ limit of 0.2 mg/l.

Most groundwater supplies contain some iron because iron is common in many aquifers and is found in trace amounts in practically all sediments and rock formations. However high concentration of iron in water imparts bitter taste, stains plumbing fixtures and cloths during laundering. The concentration of iron in the borehole water samples were 0.190mg/l, 0.133mg/l, and 0.144mg/l for BH1, BH2 and BH3 respectively. These however are lower than NSDWQ and WHO permissible limit of 0.3mg/l.

A concentration of aluminum above 0.2mg/l can result in neuro-degenerative disorder [31]. However the concentration of aluminum for all borehole water samples was below 0.01mg/l, which is below the WHO and NSDWQ permissible limit of 0.2 mg/l.

The level of sodium in drinking water is important for aesthetic consideration rather than a health hazard. More so, sodium concentrations above 200 mg/l will make the water taste salty [33]. The concentration of sodium in the borehole water samples was 18.52mg/l, 21.03mg/l and 16.70mg/l for BH1, BH2, and BH3 respectively. These values are below the WHO and NSDWQ maximum permissible limit of 200mg/l.

Copper is both an essential nutrient and a drinking water contaminant. Nevertheless, the use of water with high concentration of copper can result in gastrointestinal disturbance [34]. The concentration of copper in the borehole water samples were 0.22mg/l, 0.35mg/l and 0.50mg/l for BH1, BH2, and BH3 respectively. These values are below the WHO and NSDWQ permissible limit of 3.0mg/l and 1.0mg/l.

Total suspended solid include a wide variety of materials such as silt, clay particles, and organic matter, which can be trapped by a filter. However, high concentration of total suspended solid affects the aesthetic appeal of drinking water. The concentration of total suspended solids obtained were 3.60mg/l, 3.14mg/l and 2.94mg/l for BH1, BH2 and BH3 respectively. These values are within the WHO permissible range of 2mg/l to 5mg/l.

Lead is toxic to both the central and peripheral nervous systems, inducing subencephalopathic neurological and behavioural effects [34]. The concentration of lead in BH1 and BH2 were below the detection limit of 0.01mg/l, whereas a lead concentration of 2.27mg/l was obtained in BH3. The WHO permissible limit for lead is 0.05mg/l and that of NSDWQ is 0.01mg/l. Thus the concentration of lead obtained in BH3 is an indication of pollution. The findings of [35] confirmed significant concentrations of lead in borehole water sources in Ibadan, South-West Nigeria. Also, lead concentrations exceeding the WHO limits have also been reported by [36] in borehole water from Ikono Urban, Ikono Local Government Area, Akwa Ibom State, Nigeria. The presence of lead in borehole water may be as a result of corrosion of plumbing works containing lead, industrial and mining activities, seepage of dumpsite leachate polluted with lead to groundwater and infiltration of lead contaminated water into unsealed borehole well head during flooding.

Water containing zinc at concentration in excess of 3mg/l to 5mg/l may appear opalescent and concentration of about 4mg/l imparts an undesirable astringent taste to water [34]. The concentration of zinc obtained from borehole water samples were 2.40mg/l, 1.16mg/l, and 2.18mg/l for BH1, BH2 and BH3 respectively. These values fell below the WHO permissible limit of 5mg/l and the NSDWQ limit of 3mg/l.

Taste and odour are subjective properties which are difficult to measure [37]. Nevertheless the borehole water samples were tasteless and odourless. Therefore the presence of odour causing substances was absent. The appearance of the borehole water samples was clear. More so, the colour of the borehole water samples was below the WHO and NSDWQ permissible limit of 15 Hazen. This is due to the non-accumulation of solids and silts.

Dissolved oxygen (DO) significantly affects the activities of other chemicals in the water; it oxidizes both organic and inorganic substance thus altering their chemical and physical states and capacity for causing harm to the consumer [38]. In this study the DO of the borehole water samples were 6.34mg/l, 6.49mg/l and 3.90mg/l for BH1, BH2 and BH3 respectively. These values did not exceed the WHO permissible limit of 7 mg/l.

Ammonia can cause taste and odour problems at concentrations above 35mg/l and 1.5mg/l [39]. Ammonia in groundwater is an indicator of possible bacterial, and sewage pollution. However in this

study, the concentration of ammonia for borehole water samples was below 0.01mg/l, which is below the WHO permissible limit of 0.10mg/l.

Reactive silica is dissolved in water as the bisilicate ion making it a very weak acid. The concentration of reactive silica found in the borehole water samples were 4.52mg/l, 3.64mg/l and 4.19mg/l for BH1, BH2 and BH3 respectively. These values are well below the WHO permissible limit of 40mg/l.

Bicarbonate plays a vital role in buffering acids and ensuring that mineral water tastes pleasantly clean and refreshing. The concentration of bicarbonate found in the borehole water samples were 40.06mg/l, 51.90mg/l and 48.16mg/l for BH1, BH2 and BH3 respectively. However the concentrations recorded were far below the WHO permissible limit of 1000mg/l.

Microbiological Properties of Borehole Water Samples from Rumuodara

Total heterotrophic bacteria (THB) are non-coliform species of bacteria, and their presence in water is an indication of the presence of organic matter. The counts of total heterotrophic bacteria in the borehole water samples were above the WHO permissible of 1cfu/100ml. The highest THB count was obtained in BH2 with a value of 28.1cfu/100ml, while BH1 and BH3 had a THB count of 7cfu/100ml and 3.8 cfu/100ml respectively.

The assessment of drinking water sources for coliform microorganisms is crucial in establishing the quality of potable water as escalated amounts of coliform counts is an indication of pollution. The total coliform counts of borehole water samples were 7.5 cfu/100ml, 0.9 cfu/100ml and 3.7 cfu/100ml for BH1, BH2 and BH3 respectively. However WHO specified that potable drinking water should be devoid of total coliform. More so, the counts obtained fell below the NSDWQ permissible limit of 10cfu/100ml for total coliform.

The contamination of a water source by total coliform and total heterotrophic bacteria could be due to discharge from septic tank. Also, long term usage of boreholes may lead to deterioration of the water quality, because the pipeline may become corroded with random cracks and in most cases clogged with sediment [40]. This will allow for the passage of bacteria.

The borehole water samples recorded zero levels of fecal coliform, which conformed with the NSDWQ and WHO standard of zero fecal coliform per 100ml. Thus the absence of fecal coliform in the water samples is an indication of the absence of faecal contamination.

Finally, from the result of the microbial analysis carried out on the borehole water samples, it can be deduced that this observation supports earlier reports by [41] and [42] that most underground water sources in urban centers of Nigeria may contain substantial microbial contaminants.

CONCLUSION

The investigation of this study attests that, the physicochemical parameters of borehole water samples sourced from selected boreholes in selected communities in Rumuodara, were below the WHO and NSDWQ permissible limits, with the exception of lead (2.27mg/l) which was found in the selected borehole in Chukwuodara. More so, the results of the microbiological analysis obtained from the borehole water samples showed that all borehole water samples were void of fecal coliforms. However they contained total coliforms and total heterotrophic bacteria (THB) above the WHO permissible limit of 0 cfu/100ml for total coliform and 1 cfu/100ml for total heterotrophic bacteria, but below the NSDWQ permissible limit of 10 cfu/100ml for total coliforms.

The overall suitability of the borehole water samples for drinking was assessed with the water quality index (WQI) method. The WQI was computed from a combination of physicochemical and microbiological parameters using the NSDWQ/WHO standard. The parameters used were; aluminum,

hardness, conductivity, chloride, colour, copper, Iron, manganese, nitrate, pH, sodium, sulphate, alkalinity, turbidity, total dissolved solid, lead, total coliform, total heterotrophic bacteria and zinc.

The water quality index of the borehole water in Mgbuesilaru was rated excellent (Grade A), that of Eliowhani was rated good water quality (Grade B) and that of Chukwudara was rated unsuitable for drinking (grade E). The counts of THB (28.1 cfu/100ml) and the concentration of lead (2.27mg/l) reduced the quality of the water in the selected borehole in Eliowhani and Chukwudara respectively. This study recommends that groundwater quality should be assessed prior to consumption, to ascertain drinking water safety.

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