

## Comparative Assessment on the Physicochemical Water Quality of Wells and Boreholes in Two Rivers State Communities, Nigeria

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**Abstract:** Borehole and well are the main sources of water for residents of Rivers state known to be rich in crude oil deposit which predisposes both water sources to possible contamination with heavy and non-heavy metals with attendant health implications. This study was aimed at comparing the degree of heavy and non-heavy metals contamination as well as physicochemical properties of well and borehole water in Rumuagholu and Mgbuoshimini communities of Rivers state. A total of ninety-six samples comprising of well (48) and borehole (48) water samples were collected periodically between March-October, 2019 for analysis. All the tests were done using Standard methods. The pH, temperature, dissolved oxygen, electrical conductivity, total alkalinity, total dissolved solid, total hardness, total suspended solids, turbidity, and salinity of water samples from Mgbuoshimini were within the range of 10.36-11.13, 26.96-27.34 °C, 20.36-63.40 mg/L, 47.81-142.49 µs/cm, 85.82-299.93 mg/L, 48.29-143.76 mg/L, 115.91-237.914 mg/L, 30.15-109.33 mg/L, 6.11-20.92 NTU and 0.00-0.01 mg/L, whereas the equivalent values for water samples from Rumuagholu were 9.79-10.21, 24.46-25.64 °C, 12.12-21.84 mg/L, 47.68-143.27 µs/cm, 44.65-130.12 mg/L, 44.82-127.92 mg/L, 75.11-230.30 mg/L, 36.08-84.08 mg/L, 5.72-19.09 NTU and 0.00-0.01 mg/L, respectively. The heavy and non-heavy metals (mg/L) in the water samples from Mgbuoshimini were within the range of Cd (0.13-0.65), Cr (4.29-10.52), Cu (5.19-7.07), Fe (1.28-6.03), Pb (10.34-30.16), Mg (1.69-3.00), Zn (2.08-6.50), Br<sub>2</sub> (0.01-0.02), Cl<sub>2</sub> (0.38-1.34), PO<sub>4</sub><sup>3-</sup> (0.39-0.58), SO<sub>4</sub><sup>2-</sup> (33.11-106.86), and NO<sub>3</sub><sup>-</sup> (1.22-1.94) whereas the equivalent values (mg/L) of the water samples from Rumuagholu were 0.01-0.19, 2.07-5.46, 2.58-5.22, 0.15-1.93, 11.01-29.45, 0.42-1.10, 1.79-4.10, 0.01-0.02, 0.40-1.12, 0.28-0.39, 37.76-108.56 and 1.06-1.71, respectively. The values of some of the parameters were within the World Health Organization (WHO) limit, whereas others were not. Overall results from this study indicate that both water sources were heavily contaminated which poses a public health risk to residents of the communities. Therefore, proper waste management and disposal with adequate water treatment is recommended to guarantee that water from the well and borehole is potable and safe for drinking and domestic use.

**Keywords:** Well and Borehole Water, Heavy Metals, Non-Heavy Metals, Physicochemical Properties

### 1. INTRODUCTION

The World Health Organization (WHO) estimated that 3.4 million Africans die yearly due to consumption of unclean water and hygiene-related matters [1]. The physical, chemical and microbiological characteristics of water determines its quality [2, 3]. The quality of water is substantially affected by domestic, industrial, mining and farming activities [4]. Water is said to be potable if it is colourless, odourless, practically tasteless, as well as devoid of physical, chemical and biological contaminants [5, 6, 7]. In most part of the world, accessibility to safe drinking water has improved tremendously, yet it is estimated that in 2025 more than half of the world population will face water-related challenges [8, 9].

Ground and surface water are two major sources of water. Boreholes and hand dug wells constitute ground water sources while streams, rivers, and lakes are surface water sources [10, 11]. Estimated population of 1.5 billion persons in sub-Saharan Africa depend on groundwater as source of drinking water. Over the years, groundwater has been extensively exploited. In Nigeria, over 120 million persons use boreholes as main source of drinking water [12, 13]). Millions of persons living in semi-urban areas depend on dug wells for water supply [14]. Generally, ground water is safer and more dependable for domestic use and

agricultural irrigation than surface water. However, the proximity of pit latrines, landfills and graves to boreholes, poor agricultural practices, wrong well construction, and indiscriminate disposal of waste have been identified by many researchers as factors responsible for contamination of borehole water [7, 15]. These factors could as well contaminate well water. Generally, inorganic minerals gain entry into surface and ground water from the earth's crust, storm water run-off. The process of water treatment introduce some minerals such as sodium compound, manganese, calcium, zinc, and phosphate into the water [16]. Due to leaching of contaminants to ground water which usually happens regularly in densely populated and industrialized areas such as Rivers state, it is imperative to always monitor the quality of ground water for the sake of good health of the populace [6, 17].

The presence of heavy metals in water sources constitute one of the major contaminant. Industrial activities such as mining, agricultural, manufacturing, and oil exploration activities are sources of heavy metals that contaminate water sources. Also, natural factors, domestic and commercial practices which generate waste could also contaminate water sources with heavy metals [18, 19]. Some of the heavy metals are arsenic, mercury, lead, cadmium, copper and nickel. Since these heavy metals cannot be degraded after a long period, they tend to bioaccumulate in man and aquatic organisms [15, 20]. Excessive concentration of heavy metals in drinking water negatively affects human health [8, 13, 15, 21, 22]. During the rainy reason, leaching of rocks as well as industrial and agrochemical discharges is most likely to influence the chemical constituents and the clarity of water [15].

Rivers State is a wetland in Niger-Delta region accommodating millions of residents. The city is popularly known for extensive oil and gas activities [23, 24]. Despite the huge economic benefits, most residents of the state lack access to quality water and are likely to experience more difficulties in few years to come in having assess to safe drinking water due to alarming physicochemical properties of groundwater in the area based on current available data. Total dissolved solids up to 2900 mg/L, oil and grease reaching 71 mg/L, elevated level of iron and chloride in groundwater have recently been reported. Since a substantial population of the residents rely on groundwater as the main source of drinking water, it is important to regularly monitor and assess water quality from groundwater to generate data which will results to effective groundwater management [8, 23, 25]. Assessment of groundwater quality requires laboratory procedures, tools and various parameters [17]. Therefore, this study is aimed at comparing the physicochemical properties, heavy and non-heavy concentration of borehole and well water in Rumuagholu and Mgbuoshimini communities in Rivers State.

## 2. MATERIALS AND METHODS

### 2.1. Description of Study Area

The study was carried out in Rumuagholu and Mgbuoshimini community, both in Obio-Akpor Local Government Area of Rivers State. Obio-Akpor is bounded by Port Harcourt (Local government area) to the south, Oyigbo to the east, Ikwerre to the north, and Emohua to the west. It is located between latitudes 4°45'N and 4°60'N and longitudes 6°50'E and 8°00'E. The local government area where the borehole and well is located covers an area of 260 km<sup>2</sup>. Fig. 1 below is a map showing the communities where water samples were collected.

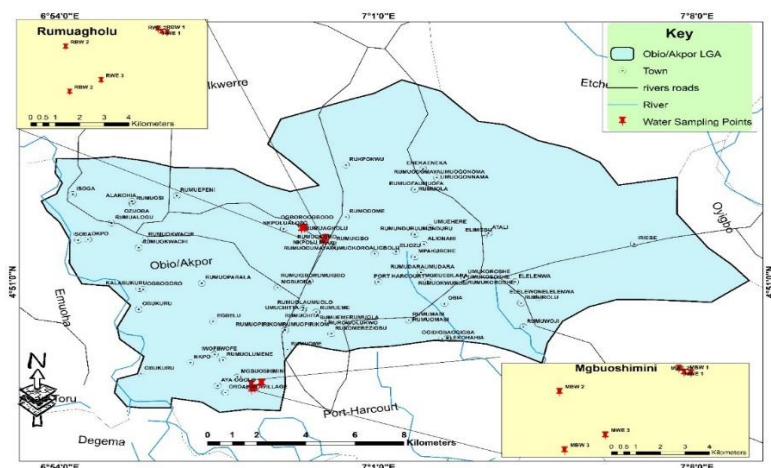


Figure1. Map of study area showing the sampled communities.

## 2.2. Sample Collection

According to the standard method adopted by Ezekwe *et al.* [21], a total of ninety-six (96) water samples were collected from boreholes and wells located in Mgbuoshimini and Rumuagholu, Rivers State between March-October, 2019; with pre-rinsed 1 litre plastic containers for the analysis of physico-chemical parameters, while Samples for heavy metal analysis were collected with nitric acid pre-rinsed 1-litre containers and treated with 2 ml nitric acid (assaying 100 %, trace metal grade, fisher scientific) prior to storage. This was done to stabilize the oxidization states of the metals. All the samples were transported with ice packs within an hour to the Microbiology Laboratory, Rivers State University for analyses.

## 2.3. Physicochemical Analysis

The physicochemical parameters of the water samples were carried out in accordance with the method of APHA [26].

### 2.3.1. Temperature and pH

The temperature of water samples was taken immediately on site using a thermometer calibrated in degree Celsius while the pH was determined using a pH meter (model HI 98130 Hanna).

### 2.3.2. Electrical Conductivity

The electrical conductivity of the water samples was measured using a digital conductivity meter model NATOP PB5 (London, UK). Standardization of the meter was performed using 0.1N KCl at 25 °C.

### 2.3.3. Dissolved Oxygen

This test was performed using Winkler's method. Manganese (II) salt, iodide (I<sup>-</sup>) and hydroxide (OH<sup>-</sup>) ions were added in excess to the samples causing a white precipitate of Mn(OH)<sub>2</sub> to form. The precipitate formed was oxidized by the dissolved oxygen in the water sample which turn into a brown manganese precipitate and hydrochloric acid was added to acidify the solution. The brown precipitate was then converted from iodide ion (I<sup>-</sup>) to iodine. The amount of dissolved oxygen was directly proportional to the titration of iodine with a thiosulphate solution. Three hundred millilitre (300 ml) BOD bottles were filled with water samples respectively. Two millilitre (2 ml) of manganese sulphate and 2 ml of alkali-iodide-azide solution was added by inserting a pipette just below the surface of the liquid. The bottles were stoppered to avoid air being introduced, then the content of the bottles were properly mixed by inverting them several times. The bottles were left to stand for 3 min. The presence of oxygen was indicated by the formation of brownish-orange precipitate. Two millilitre (2 ml) of H<sub>2</sub>SO<sub>4</sub> was added to the samples, then properly mixed again and inverted to dissolve the precipitate. Two hundred and one millilitre (201 ml) of the samples was measured into a clean 250 ml conical flask and titrated against sodium thiosulphate solution (Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>.5H<sub>2</sub>O) using the starch indicator until the solution turned colourless.

### 2.3.4. Turbidity

The turbidity of the water samples was measured using a digital turbidity meter (2100AN HARCH Model). A clean deionized water was used to standardize the turbidity meter before introducing the test samples. The turbidity reading of each water sample was then recorded.

### 2.3.5. Total Dissolved Solid

This test was performed using a conductivity meter. The automated menu of the conductivity meter was switched on to total dissolved solid. A volume of 100 cm<sup>3</sup> of the sample was poured into the beaker and the electrode which is part of the conductivity meter was introduced into the sample. The result of the total dissolved solid of the water sample shown on the display were noted [26].

### 2.3.6. Total Suspended Solids

The total suspended solids in the water samples were determined by simple calculation shown below:

$$\text{Total suspended solids} = \text{Total solids} - \text{Total dissolved solids}$$

### 2.3.7. Total Hardness

Water sample measuring 10 cm<sup>3</sup> was pipetted into a conical flask. 1 cm<sup>3</sup> of buffer solution (NH<sub>4</sub>Cl) of pH 10 and 3 drops of Erichrome black T indicator were added to the flask. The mixture was then titrated

with 0.01M ethyl diamine tetra acetic acid (EDTA) until the colour changed from wine red to blue. The procedure was repeated two more times to obtain the average titer value [27].

#### *2.3.8. Total Alkalinity*

This test was done by measuring 100cm<sup>3</sup> of water into a beaker which had 3 drops of phenolphthalein indicator inside it. The solution was titrated against 0.1N HCl until the colour changed from pink to colourless [28].

#### *2.3.9. Salinity*

The measurement of salinity of the water samples collected in sterile plastic bottles was done using the standard method recommended by APHA [26]. To avoid interference of sulphate and sulphide, 1 ml of hydrogen peroxide was added to 100 ml of water sample. The pH of the sample was adjusted to 7.0 with dilute H<sub>2</sub>SO<sub>4</sub> or NaOH since it is only at neutral or alkaline pH that potassium chromate can indicate the end point of the silver nitrate (AgNO<sub>3</sub>) titration of chloride.

### **2.4. Determination of Non-Heavy Metals**

#### *2.4.1. Chloride*

This test was performed to determine the total chlorine content of the water sample using the HACH Test Kit Model CN66/66F/66T). A colour viewing tube was filled to the 5 mL mark with the water sample. Also, another viewing tube was filled to the 5-mL mark with the water sample. Then, clippers was used to open one DPD Total chlorine reagent powder pillow, and the content was emptied inside the water sample. It was gently swirled to achieve a homogenous solution, allowed to stand for three minutes and the results were recorded.

#### *2.4.2. Bromide*

Hanna Bromine Test Kit (HI 3830) was used to determine the level of bromine in the water samples. Seven drops of Reagent 1 and 3 drops of Reagent 2 was added to the colour comparator cube, carefully mixed by swirling the comparator cube in tight circle, followed by the removal of the cap from the plastic vessel. The plastic vessel was rinsed, then filled to the 25 mL mark with water sample and transferred to the colour comparator cube. The cap of the comparator cube was replaced and its content thoroughly mixed by inverting it several times. The colour intensity of the solution was determined i.e. (bromine concentration) and the results were recorded in mg/L (ppm) bromine [29].

#### *2.4.3. Sulphate*

The turbidimetric method was adopted in determining the level of sulphate in the water samples. One hundred millilitre (100 ml) of the sample was measured into a 250 mL Erlenmeyer flask. Five millilitre (5 ml) of conditioning reagent was added to the content of the flask, then placed on a magnetic stirrer for proper mixing. A spoonful of barium chloride crystals was added, immediately timed, and stirred at a constant speed for one minute. A portion of the solution was poured into the absorption cell of the photometer, and the turbidity was measured at 30 sec intervals for 4 min. Usually, maximum turbidity occurs within 2 min and the reading remains constant thereafter for 3 - 10 min.

#### *2.4.4. Phosphate*

Standards are prepared using a phosphate standard solution of 3 mg/L as phosphate (PO<sub>4</sub><sup>3-</sup>). This is equivalent to a concentration of 1 mg/L as phosphorus. The concentration and result from the procedure were expressed in mg/L. Six standard concentrations were prepared for every sampling date in the range of expected results. Six 25-mL volumetric flasks one for each standard was labelled 0.00, 0.04, 0.08, 0.12, 0.16, and 0.20. About 30 mL of the phosphate standard solution was poured into a 50 mL beaker. 1-, 2-, 3-, 4-, and 5-mL Class A volumetric pipette was used to transfer a corresponding volume of phosphate standard solution to each 25-mL volumetric flask.

#### *2.4.5. Nitrate*

An aliquot of 2 ml of 0.1M NaOH solution and 1 ml of colour developing reagent was added to a 50 ml water sample. The mixture was allowed to stand for 20 min, and the nitrate concentration was determined at wavelength 543 nm of absorbance.



## 2.5. Determination of Heavy Metals

The concentration (mg/L) of Pb, Cu, Cr, Cd, Mg, Fe and Zn in the water samples was determined using the Atomic absorption spectrophotometer (Flame AAS) Model: S4=71096. The flame used for the analysis was air-acetylene mixture. Standard solutions ranging from 0.2 - 5.0 mg/L was prepared for calibration curves of the various metals. The hollow cathode lamp for the respective metals was installed. A wavelength dial as specified by the analytical methodology was set. The instrument was turn on, and the hollow cathode lamp was applied which started becoming warm until energy source was stabilized for 10 - 20 min. A 10 cm, single-slot burner head was used by direct air-acetylene flames method. In conclusion the concentrated and digested samples were then aspirated and the actual concentrations were obtained by referring to the calibration graph and necessary calculations.

## 2.6. Data Analysis

The means of triplicate analysis for each parameter was determined and standard deviation of the means was calculated.

## 3. RESULTS

The physicochemical parameter of water samples from three (3) boreholes and three (3) wells in Mgbuoshimini community presented in Table 1 shows that pH, dissolved oxygen (DO) and turbidity concentrations were above the WHO limit; while temperature was within the WHO limit and electrical conductivity (EC), total alkalinity (TA), total dissolved solid (TDS), total hardness (TH), and total suspended solids (TSS), of water samples from the wells boreholes were far below the WHO limit except total alkalinity (TA) of MBWE1 and MBWE2 which are higher than the WHO limit and salinity almost at zero (0) concentration.

**Table 1.** Physicochemical properties of well and borehole water from Mgbuoshimini community

Parameter	Unit	MBWE1	MBWE2	MBWE3	MBBO1	MBBO2	MBBO3	WHO Limit	Remarks
pH	-	10.86±9.64	10.99±9.68	11.13±9.78	10.36±9.37	10.51±9.31	10.61±9.24	6.5-8.5	AL
Temperature	°C	26.96±0.90	27.16±0.31	27.04±0.84	27.04±0.90	27.34±0.71	26.98±0.84	25-30	WL
Dissolved Oxygen (DO)	mg/L	63.40±131.21	62.21±124.07	40.63±82.42	21.66±38.32	20.36±35.52	28.13±50.95	5.0-10.0	AL
Electrical conductivity (EC)	µS/cm	142.49±76.07	155.92±83.30	129.73±69.65	47.81±26.29	107.83±57.26	61.87±32.18	500	WL
Total Alkalinity (TA)	mg/L	299.93±16.58	271.95±14.05	195.59±35.79	97.03±40.81	85.82±61.22	121.53±16.62	200	WL (MBWE1 & MBWE2)
Total Dissolved solid (TDS)	mg/L	118.59±42.05	143.76±34.56	106.46±45.29	48.29±25.40	94.35±35.33	59.94±21.05	250-500	WL
Total Hardness (TH)	mg/L	237.914±140.21	225.34±126.02	201.38±112.67	130.88±73.26	150.99±84.52	115.91±65.01	500	WL
Total Suspended Solid (TSS)	mg/L	86.03±24.74	109.33±32.53	68.70±24.72	30.15±20.87	47.25±26.91	53.84±13.95	1000	WL
Turbidity (NTU)	NTU	18.08±40.40	20.92±46.63	16.88±37.65	6.11±13.49	8.54±18.99	12.52±27.91	5	AL
Salinity	mg/L	0.01±0.00	0.01±0.00	0.01±0.01	0.00±0.00	0.00±0.00	0.00±0.00	200-250	WL

**Key:** AL-Above limit set by World Health Organization (WHO); WL- Within limit set by WHO. MBWE 1, MBWE 2, and MBWE 3 – Well water 1, Well water 2, and Well water 3 located in Mgbuoshimini community; MBBO 1, MBBO 2, MBBO 3-Borehole 1, Borehole 2, Borehole 3 located in Mgbuoshimini community

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Result from Table 2 shows the physicochemical properties of water samples from three (3) boreholes and three (3) wells located in Rumuagholu Community. The values obtained indicate that pH, dissolved oxygen (DO) and turbidity concentrations were above the WHO limit; while temperature was within the WHO limit and electrical conductivity (EC), total alkalinity (TA), total dissolved solid (TDS), total hardness (TH), and total suspended solids (TSS), of water samples from the wells boreholes were far below the WHO limit and salinity almost at zero (0) concentration.

**Table 2.** Physicochemical properties of well and borehole water from Rumuagholu community

Parameter	Unit	RMWE1	RMWE2	RMWE3	RMBO1	RMBO2	RMBO3	WHO Limit	Remarks
pH	-	9.95±8.98	10.14±8.87	9.79±9.10	10.21±9.43	10.04±8.93	10.20±9.07	6.5-8.5	AL
Temperature	°C	25.64±1.51	24.46±0.46	25.10±1.11	25.12±1.09	24.62±0.56	25.14±1.06	25-30	WL
Dissolved Oxygen (DO)	mg/L	21.84±37.78	19.05±29.02	21.14±35.38	12.84±20.78	17.07±27.86	12.12±15.95	5.0-10.0	AL
Electrical conductivity (EC)	µS/cm	143.27±77.12	116.81±63.51	96.15±50.99	68.46±35.25	47.68±24.79	62.26±31.81	500	WL
Total Alkalinity (TA)	mg/L	100.71±48.64	92.30±68.68	130.12±112.09	62.79±42.54	72.66±43.17	44.65±30.93	200	WL
Total Dissolved solid (TDS)	mg/L	127.92±36.11	102.42±37.74	85.33±35.66	67.21±23.78	44.82±19.62	58.58±20.53	250-500	WL
Total Hardness (TH)	mg/L	149.05±83.26	168.85±94.31	230.30±137.41	104.03±58.43	114.87±64.38	75.11±42.23	500	WL
Total Suspended Solid (TSS)	mg/L	72.61±36.52	47.34±31.5	36.08±30.86	46.92±22.27	50.94±7.89	84.08±4.56	1000	WL
Turbidity (NTU)	NTU	13.97±30.39	9.78±21.63	5.72±12.60	9.68±21.55	12.49±27.87	19.09±42.60	5	AL
Salinity	mg/L	0.01±0.00	0.01±0.00	0.01±0.01	0.00±0.00	0.00±0.00	0.00±0.00	200-250	WL

**Key:** AL-Above limit set by World Health Organization (WHO); WL- Within limit set by WHO. RMWE1, RMWE2, and RMWE3 – Well water 1, Well water 2, and Well water 3 located in Rumuagholu community; RMBO 1, RMBO 2, RMBO 3-Borehole 1, Borehole 2, Borehole 3 located in Rumuagholu community

Result obtained in Table 3 shows the concentration of heavy metals and non-heavy metals in water samples obtained from three (3) wells and three (3) boreholes in Mgbuoshimini community which indicate that Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe<sup>2+</sup>) and Lead (Pb) were above the WHO limit; while Magnesium (Mg<sup>2+</sup>), Bromide (Br), Chloride (Cl<sup>-</sup>), Sulphate (SO<sub>4</sub><sup>2-</sup>) and Nitrate (NO<sub>3</sub><sup>-</sup>) were below the WHO limit. Furthermore, Zinc (Zn) and Phosphate (PO<sub>4</sub><sup>3-</sup>) were above the WHO limit except in locations (MBBO1 & MBBO2) for both heavy metals and Zinc (Zn) in location (MBWE3).

**Table 3.** Concentration of heavy and non-heavy metals present in well and borehole water from Mgbuoshimini community

Parameter	Unit	MBWE1	MBWE2	MBWE3	MBBO1	MBBO2	MBBO3	WHO Limit	Remarks
Cadmium (Cd)	mg/L	0.65±1.27	0.32±0.69	0.53±0.88	0.20±0.38	0.23±0.48	0.13±0.23	0.003	AL
Chromium (Cr)	mg/L	7.50±4.15	5.77±3.22	4.29±2.32	5.69±3.16	4.72±2.63	10.52±5.87	0.05	AL

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Copper (Cu)	mg/L	6.93±1.36	6.17±0.59	6.55±0.68	5.74±0.77	7.07±0.66	5.19±4.45	2	AL
Iron (Fe <sup>2+</sup> )	mg/L	6.03±3.079	3.68±1.6	3.49±1.22	2.73±0.62	3.43±0.85	1.28±0.088	0.3	AL
Lead (Pb)	mg/L	30.16±60.96	26.43±55.72	21.33±42.99	10.34±21.24	15.69±32.66	19.82±43.17	0.01	AL
Magnesium (Mg <sup>2+</sup> )	mg/L	1.69±2.59	1.92±2.23	2.41±2.48	2.38±1.68	3.00±2.44	1.54±0.93	20-125	WL
Zinc (Zn)	mg/L	6.50±0.77	5.32±0.61	3.68±0.48	2.08±0.52	2.85±0.63	3.55±1.23	3.0	AL (Except MBBO1 & MBBO2)
Bromide (Br)	mg/L	0.02±0.01	0.02±0.01	0.02±0.01	0.01±0.00	0.01±0.00	0.01±0.00	0.1	WL
Chloride (Cl <sub>2</sub> )	mg/L	1.34±2.96	1.21±2.67	0.78±1.73	0.38±0.85	0.59±1.30	0.83±1.84	250	WL
Phosphate (PO <sub>4</sub> <sup>3-</sup> )	mg/L	0.58±0.15	0.56±0.18	0.41±0.08	0.50±0.19	0.39±0.20	0.56±0.15	0.5	AL (Except MBWE3, MBBO1 & MBBO2)
Sulphate (SO <sub>4</sub> <sup>2-</sup> )	mg/L	106.86±59.67	96.01±53.42	73.50±41.12	33.11±19.05	53.75±30.36	74.00±41.38	250-500	WL
Nitrate (NO <sub>3</sub> <sup>-</sup> )	mg/L	1.69±1.96	1.94±2.94	1.22±1.78	1.49±2.02	1.44±2.11	1.77±2.42	10	WL

**Key:** AL-Above limit set by World Health Organization (WHO); WL- Within limit set by WHO. MBWE1, MBWE2, and MBWE3 – Well water 1, Well water 2, and Well water 3 located in Mgbuoshimini community; MBBO1, MBBO2, MBBO 3-Borehole 1, Borehole 2, Borehole 3 located in Mgbuoshimini community

The concentration of metals and non-metals in water samples obtained from three (3) wells and three (3) boreholes in Rumuagholu Community are presented in Table 4. The values obtained reveal that Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe<sup>2+</sup>), and Lead (Pb) were above the WHO limit while Magnesium (Mg<sup>2+</sup>), Bromide (Br), Chloride (Cl<sub>2</sub>), Phosphate (PO<sub>4</sub><sup>3-</sup>), Sulphate (SO<sub>4</sub><sup>2-</sup>) and Nitrate (NO<sub>3</sub><sup>-</sup>) were below the WHO limit. However, Iron (Fe<sup>2+</sup>) concentrations were above the WHO limit except in location (RMWE1) while Zinc (Zn) concentrations were below the WHO limit except in location (RMWE1, RMWE2 and RMBO1).

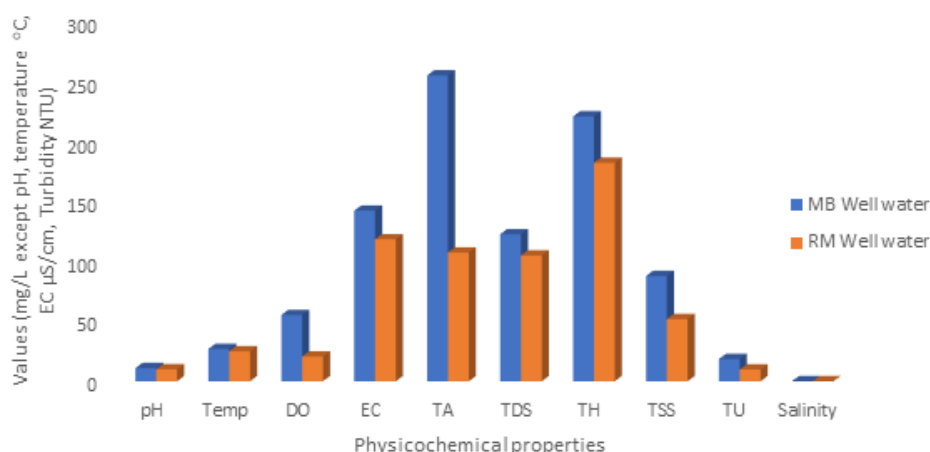
**Table 4.** Concentration of heavy and non-heavy metals present in well and borehole water from Rumuagholu community

Parameter	Unit	RMWE1	RMWE2	RMWE3	RMBO1	RMBO2	RMBO3	WHO Limit	Remarks
Cadmium (Cd)	mg/L	0.05±0.01	0.19±0.34	0.16±0.23	0.06±0.09	0.04±0.07	0.01±0.00	0.003	AL
Chromium (Cr)	mg/L	5.46±3.02	4.50±2.50	5.05±2.79	3.52±1.95	2.07±1.15	3.13±1.75	0.05	AL
Copper (Cu)	mg/L	5.22±0.89	3.05±1.44	2.58±2.08	2.53±1.04	3.29±0.39	2.92±0.55	2	AL
Iron (Fe <sup>2+</sup> )	mg/L	0.15±0.02	0.37±0.19	0.89±0.44	1.04±0.57	0.94±0.24	1.93±0.97	0.3	AL (Except RMWE1)
Lead (Pb)	mg/L	24.90±55.59	29.45±64.11	26.07±57.06	11.01±24.13	13.79±30.48	11.88±26.56	0.01	AL
Magnesium (Mg <sup>2+</sup> )	mg/L	1.06±2.10	0.55±1.04	0.42±0.69	0.44±0.91	1.10±1.32	0.69±1.11	20-125	WL
Zinc (Zn)	mg/L	4.10±2.24	3.62±1.67	2.39±0.71	3.21±1.05	1.79±0.41	2.91±0.28	3.0	WL (Except RMWE1, RMWE2 & RMBO1)

## Comparative Assessment on the Physicochemical Water Quality of Wells and Boreholes in Two Rivers State Communities, Nigeria

Bromide (Br)	mg/L	0.02±0.01	0.02±0.01	0.02±0.01	0.01±0.00	0.01±0.00	0.01±0.00	0.1	WL
Chloride (Cl <sub>2</sub> )	mg/L	1.12±2.48	0.95±2.11	0.56±1.24	0.76±1.68	0.40±0.89	0.61±1.36	250	WL
Phosphate (PO <sub>4</sub> <sup>3-</sup> )	mg/L	0.39±0.15	0.32±0.12	0.36±0.09	0.29±0.08	0.28±0.05	0.34±0.13	0.5	WL
Sulphate (SO <sub>4</sub> <sup>2-</sup> )	mg/L	95.08±52.97	108.56±60.72	98.82±55.27	37.76±21.60	49.01±27.75	44.57±24.79	250-500	WL
Nitrate (NO <sub>3</sub> <sup>-</sup> )	mg/L	1.46±2.99	1.71±3.57	1.78±2.97	1.06±2.09	1.49±2.97	1.40±2.91	10	WL

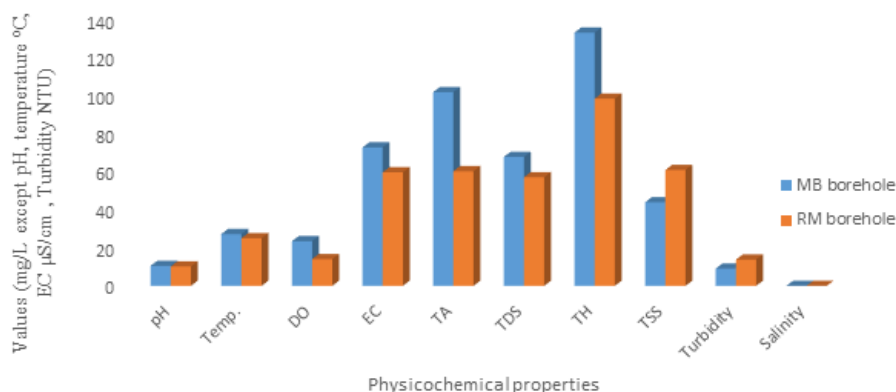
**Key:** AL-Above limit set by World Health Organization (WHO); WL- Within limit set by WHO. RMWE1, RMWE2, and RMWE3 – Well water 1, Well water 2, and Well water 3 located in Rumuagholu community; RMBO1, RMBO2, RMBO3-Borehole 1, Borehole 2, Borehole 3 located in Rumuagholu community



**Figure 2.** Average physicochemical properties of water samples from three wells each located in Mgbuoshimini (MB) and Rumuagholu (RM) communities.

**Key:** Temp-Temperature; DO-Dissolved oxygen; EC-Electrical conductivity; TA-Total alkalinity; TDS-Total dissolved solids; TH-Total hardness; TSS-Total soluble solid; TU-Turbidity

Depicted in Figure 2 is the average physicochemical properties of water samples from three wells located in Mgbuoshimini and Rumuagholu communities. The average mean values obtained from the result reveal that pH, temperature, dissolved oxygen (DO), electrical conductivity (EC), total alkalinity (TA), total dissolved solid (TDS), total hardness (TH), total soluble solid (TSS), turbidity and salinity of water samples from three (3) wells in Mgbuoshimini community were 10.99, 27.05 °C, 55.41 mg/L, 142.71 µS/cm, 255.82 mg/L, 122.94 mg/L, 221.54 mg/L, 88.02 mg/L, 18.63 NTU and 0.01 mg/L while the equivalent values for water samples from three wells in different locations in Rumuagholu were 9.96, 25.07 °C, 20.68 mg/L, 118.74 µS/cm, 107.71 mg/L, 105.22 mg/L, 182.73 mg/L, 52.01 mg/L, 9.82 NTU and 0.01 mg/L, respectively.

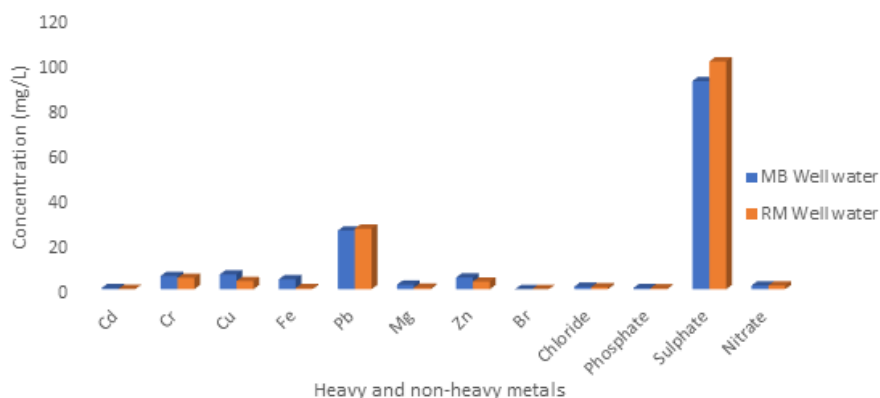


**Figure 3.** Average physicochemical properties of water samples from three boreholes each located in Mgbuoshimini (MB) and Rumuagholu (RM) communities.



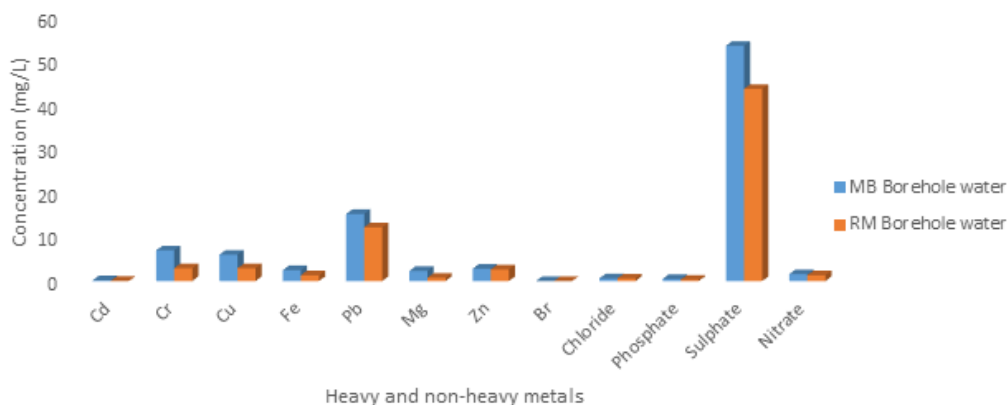
**Key:** Temp-Temperature; DO-Dissolved oxygen; EC-Electrical conductivity; TA-Total alkalinity; TDS-Total dissolved solids; TH-Total hardness; TSS-Total soluble solid

Figure 3 represent the average physicochemical properties of water samples from three (3) boreholes located in both communities. The average pH, temperature, DO, EC, TA, TDS, TH, TSS, Turbidity, and Salinity of water samples from three (3) boreholes located in different points in Mgbuoshimini community were 10.49, 27.12 °C, 23.38 mg/L, 72.50 μS/cm, 101.46 mg/L, 67.53 mg/L, 132.59 mg/L, 43.75 mg/L, 9.06 NTU and 0.00 while the equivalent values for water samples from three (3) boreholes located in three different sites were 10.15, 24.96 °C, 14.01 mg/L, 59.47 μS/cm, 60.03 mg/L, 56.87 mg/L, 98.00 mg/L, 60.65 mg/L, 13.75 NTU, and 0.00 mg/L, respectively.



**Figure4.** Average concentration of heavy and non-heavy metals in water samples from three wells each located in Mgbuoshimini (MB) and Rumuagholu (RM) communities.

The average concentration of heavy and non-heavy metals present in water samples from three (3) wells located in Mgbuoshimini and Rumuagholu communities is depicted in Figure 4. The Cd, Cr, Cu, Fe, Pb, Mg, Zn, Br, Cl<sub>2</sub>, PO<sub>4</sub><sup>3-</sup>, SO<sub>4</sub><sup>2-</sup>, and NO<sub>3</sub><sup>-</sup> detected in water samples from three wells located at different points in Mgbuoshimini community were 0.5 mg/L, 5.85 mg/L, 6.55 mg/L, 4.4 mg/L, 25.97 mg/L, 2.01 mg/L, 5.17 mg/L, 0.02 mg/L, 1.11 mg/L, 0.52 mg/L, 92.12 mg/L, and 1.62 mg/L whereas the equivalent values in water samples from three (3) wells located in Rumuagholu were 0.13 mg/L, 5.0 mg/L, 3.62 mg/L, 0.47 mg/L, 26.81 mg/L, 0.68 mg/L, 3.37 mg/L, 0.02 mg/L, 0.88 mg/L, 0.36 mg/L, 100.82 mg/L and 1.65 mg/L, respectively.



**Figure5.** Average concentration of heavy and non-heavy metals in water samples from three boreholes each located in Mgbuoshimini (MB) and Rumuagholu (RM) communities.

The average concentration of heavy and non-heavy metals present in water samples from three (3) boreholes also located in both communities is depicted in Figure 5. The values for heavy and non-heavy metals detected in water samples from three boreholes located at different points in Mgbuoshimini community shows that Cd (0.19 mg/L), Cr (6.98 mg/L), Cu (6.00 mg/L), Fe (2.48 mg/L), Pb (15.28 mg/L), Mg (2.31 mg/L), Zn (2.83 mg/L), Br (0.01 mg/L), Cl<sub>2</sub> (0.6 mg/L), PO<sub>4</sub><sup>3-</sup> (0.48 mg/L), SO<sub>4</sub><sup>2-</sup> (53.62 mg/L) and NO<sub>3</sub><sup>-</sup> (1.57 mg/L) whereas the equivalent values for water samples from three (3) boreholes sited in three different locations in Rumuagholu were 0.037 mg/L, 2.91 mg/L, 2.91 mg/L, 1.3 mg/L, 12.23 mg/L, 0.74 mg/L, 2.64 mg/L, 0.01 mg/L, 0.59 mg/L, 0.3 mg/L, 43.78 mg/L and 1.32 mg/L, respectively.

#### 4. DISCUSSION

Presented in this study are the physicochemical properties of groundwater and the heavy and non-heavy metals concentrations in the samples obtained from three (3) wells and three (3) boreholes located in Mgbuoshimini and Rumuagholu communities. The values of pH, temperature, dissolved oxygen (DO), electrical conductivity (EC), total alkalinity (TA), total dissolved solid (TDS), total hardness (TH), total suspended solid (TSS), and turbidity of well water samples obtained from Mgbuoshimini is higher than equivalent values for well water samples obtained from Rumuagholu community. This result is an indication that the quality of well water from Rumuagholu is better than what was obtainable from Mgbuoshimini community. As for the borehole water samples obtained from Mgbuoshimini, the respective values for pH, temperature, DO, EC, TA, TDS, and TH were higher than equivalent values for borehole water samples from Rumuagholu community. However, the turbidity and salinity of borehole water samples from Rumuagholu were higher than the equivalent values from Mgbuoshimini community. Considering the values for the various physicochemical parameters of water samples from the boreholes, the samples obtained from Rumuagholu is considered as a better quality water than what was obtainable from Mgbuoshimini community. Notably, the salinity of well water samples and borehole water samples from the two communities were the same.

pH is a significant factor that impacts many biological and chemical processes. It is a water quality assessment parameter which is very important in evaluating water supply and treatment [30]. Our results show that pH of all the water samples from the wells and boreholes located in the two communities range from 9.79-11.13. The values were above the recommended limit by WHO which is 6.5-8.5. The well water samples from Mgbuoshimini is slightly more alkaline compared with borehole water samples from the same community whereas it was the reverse in the case of water samples from Rumuagholu community. In a related study, Ebong *et al.* [11] reported that the pH of borehole water sampled from different points in Mgbuoshimini is within the range of 4.31-4.73. Alex *et al.* [23] reported that pH of groundwater in Elioizu community, Port Harcourt is within the range of 5.5-8.0. Ezekwe *et al.* [21] also reported a circum-neutral pH of 6.3-7.3 in run downstream. These reports are not in agreement with the findings from this study. According to Popoola *et al.* [17], high pH of water sources could be as a result of bicarbonates that forms part of the raw materials essential for production which eventually reach the soil, later percolates into groundwater which is aided by rainfall. The pH of natural water range between 5.5 and 9.0 [25]. It has been established that high alkalinity of water is responsible for swelling of hair fibres as well as gastrointestinal irritation [17]. Since most of the minerals present in rocks underlying any area are soluble in water under appropriate geochemical condition, the pH of available water body in that area is affected based on the mineralogical and geochemical characteristics of the rocks. Quite few of the unseen dissolved minerals as well as organic constituents found in ground water are highly toxic. Majority of them are not only harmless but also beneficial [25].

During quality assessment of water suitable for human consumption, the temperature of the water samples is among the important physicochemical parameters considered. Also, the rate at which chemical reactions occurs, the reduction in solubility of gases, amplifications of tastes and colours of water are the activities that take place in the water body which is controlled by temperature [25]. In this study, the temperature of both well and borehole water from the two communities range between 24.46-27.34 °C which is within the WHO set limit. Meanwhile, the temperature range of borehole and well water samples from Rumuagholu community (24.46-25.64 °C) is lower than what was obtainable (26.96-27.34 °C) in borehole and well water samples from Mgbuoshimini community. The temperature of water samples reported in this study is in agreement with a similar study carried out by Alex *et al.* [23].

Dissolved oxygen (DO) refers to the level of free, non-compound oxygen present in water. It is an important parameter used in assessing the quality of water since it influences the organisms living in a water body. Usually, the level of oxygen in water decreases when there is an increase in nutrients and organic materials from industrial wastewater, sewage discharges, and runoff from land [31]. The results obtained from this study shows that DO of borehole water samples which range from 12.12-20.36 mg/L is lower than what was encountered in the well water samples (19.05-63.40 mg/L). Meanwhile, both results were above the limit set by WHO which is 5.0-10.0 mg/L. Higher DO in the well water samples compared with the borehole water samples is an indication that larger population of bacteria were present in the water samples from the borehole that utilized more quantity of dissolved oxygen compared with the well water. It is also possible that fertilizer runoffs from lawns and farmlands

infiltrated the boreholes and reduced the DO compared with the wells. The DO in the water samples reported in this study is comparable with values reported by Okonkwo *et al.* [32]. According to Adesakin *et al.* [25], the amount of dissolved oxygen in water is influenced by temperature of the water. Warm water dissolve lesser amount of oxygen compared with cold water. Dissolved oxygen is a parameter which is of high significance to all living organisms. Direct diffusion from air or photosynthesis by autotrophs are the possible means DO in water bodies is produced. Although DO is not directly linked to any hazard that affects humans, it affects the chemicals present in the sample [25].

Electrical conductivity (EC) is the ability of a solution to conduct an electrical current that is directed by the migration of solutions which is dependent on the nature and number of the ionic species in the same solution [33]. It is an appropriate tool used in assessing the purity of water. Our result shows that the electrical conductivity of well water (96.15-155.92  $\mu\text{S}/\text{cm}$ ) and borehole water (47.68-107.83  $\mu\text{S}/\text{cm}$ ) were within the permissible limit of 500  $\mu\text{S}/\text{cm}$  set by the WHO. Going by the result of EC of the water samples, they are suitable for domestic use, irrigation and other purposes. Low conductivity result reported in this study is an indication that small quantity of dissolved inorganic substances in ionized form could reach the water source from their surface catchment [25]. The EC of the water samples is in agreement with the findings of Olubanjo *et al.* [8] from a related study involving water samples from wells and boreholes. However, the values reported by the researchers is above the results reported in this study. Research findings by Ebong *et al.* [11] shows that the electrical conductivity of borehole water sampled from different points in Mgboushimini community is within the range of 331-533  $\mu\text{S}/\text{cm}$ . The electrical conductivity of the well water is in agreement with Adesakin *et al.* [25] which reported that EC of well water in Nigeria is within the range of 22-315  $\mu\text{S}/\text{cm}$ .

Total alkalinity (TA) is the measure of substances in water which gives it the ability to neutralize acidity. It acts like a buffer against pH, keeping it fairly constant thereby protecting the water from acid rain [34]. Alkalinity in natural water is mainly due to the presence of carbonates or bicarbonates [35]. The results obtained from this study indicate that total alkalinity of water samples from the boreholes were lower than what was obtainable in water samples from the wells. As recommended by WHO, the acceptable limit of total alkalinity in water is 200 mg/L. This requirement was met by water samples obtained from wells and boreholes located in Rumuagholu community which range between 44.65-130.12 mg/L. Similarly, borehole and well water samples obtained from Mgboushimini met the WHO requirement for total alkalinity which range between 85.82-195.59 mg/L except two (2) well water samples MBWE1 and MBWE2. In a related study, Ebong *et al.* [11] reported that total alkalinity of borehole water sampled from different points in Mgboushimini is 4 mg/L.

The inorganic matter and small amounts of organic matter present in water in form of a solution is referred as total dissolved solid (TDS). It is a combination of cations and anions present in water, bicarbonate, carbonate, sulphate, phosphate, magnesium, nitrate, calcium, organic ions and other ions [25]. When the total dissolved solids in water is high, it reduces the water clearness which contribute in reducing photosynthetic activities, perhaps lead to increase in temperature of the water [36]. According to Adesakin *et al.* [25], the taste of drinking water is affected if the TDS exceed the WHO limit which is 250-500 mg/L. Our results shows that TDS of water samples from the boreholes were lower than what was obtainable in water samples from the wells. The range of TDS in water samples from the well and borehole is 85.33-143.76 mg/L and 44.65-94.35 mg/L, respectively. The values reported in this study were far below the limit stipulated by WHO. Zige *et al.* [14] associated low TDS of water samples from boreholes to natural source, far less influence of any saline intrusion due to remoteness, industrial wastewater, sewage, urban run-off as well as type of chemicals used in treatment process. The TDS of borehole water sampled from different points in Mgboushimini reported by Ebong *et al.* [11] is within the range of 229-373 mg/L.

The presence of dissolved calcium and magnesium salts significantly contributes to the total hardness of natural waters. The total hardness of water vary over a wide range due to seasonal variations of water [37]. According to Durfor and Becker [38], four categories of water hardness are soft (0 – 60 mg/L), moderate (60-120 mg/L), hard (121-180 mg/L) and very hard (> 180 mg/L). Therefore, the well water samples from the two communities is hard and very hard considering the result obtained which were within the range of 149.05-237.914 mg/L. Meanwhile, the values for borehole water samples were within the range of 75.11-150.99 mg/L which is considered as hard. All the water samples from the boreholes and wells were within the WHO limit for total hardness which is 500 mg/L.

Total suspended solids (TSS) in water is of great importance in assessing the quality of water. The presence of solids could consist of algal growths which is an indication of severe eutrophic conditions. This parameter (TSS) may also give an indication on the level of discharge of washings from quarries. The result obtained from this study shows that TSS of both well and borehole water samples from the two communities were within the WHO limit (1000 mg/L). The values falls within the range of 36.08-86.03 mg/L. Meanwhile, the TSS of water samples from the wells located in the two communities is higher than the values obtained for borehole water with few exceptions. A study carried out by Olubanjo *et al.* [8] reported that TSS of water samples from wells located in Ondo state during rainy and dry season is within the range of 0.00-8.00 mg/L and 0.0-10.00 mg/L while the values encountered in water samples from boreholes during rainy and dry seasons is within the range of 0.00-4.00 mg/L and 0.00-6.00 mg/L, respectively. Their research findings is not in agreement with ours possibly because of low industrialization, population, and anthropogenic activities in Ondo state compared with Rivers state.

The cloudiness of water due to the presence of varieties of particles influences its turbidity. This is a key parameter in drinking water analysis. It is also related to the population of disease-causing microorganisms present in water which could come from soil runoff [39]. The standard recommended maximum turbidity limit set by WHO for drinking water is 5 nephelometric turbidity units (NTU). Turbidity values for well and borehole water samples which was in the range of 5.72-20.92 NTU and 6.11-19.09 NTU, respectively is above the WHO limit. In a related study, Ebong *et al.* [11] reported zero (0) NTU as the turbidity of borehole water sampled from different points in Mgboushimini community which is not in agreement with the result reported in this study.

Salinity is a test to determine the level of salt content (the greater part is chloride equivalent) which may render water unsuitable for domestic, agricultural or industrial use. The values for salinity of water samples from wells and boreholes is 0.01 mg/L and 0 mg/L, respectively. Both results were within the limit set by WHO (200-250 mg/L).

Cadmium is an extremely toxic heavy metal even at low concentration. It occurs naturally in rocks and soils from where it reaches the groundwater or surface water. The concentration of Cd in the water samples from the wells and boreholes is within the range of 0.05-0.65 mg/L. The values exceeded the limit of 0.003 mg/L recommended by WHO. In a related study, Udousoro and Austin [9] reported a similar result which involved assessment of heavy metals in groundwater located in a community in Rivers state. However, Ezekwe *et al.* [21] reported Cadmium value of 12.11-12.16 mg/L which is above the recommended limit by WHO. Reports by Okonkwo *et al.* [32] and Akpoveta *et al.* [40] reported values lower than what was obtainable in this study. Excess intake of cadmium has damaging effect in human health. It is associated with cancer, hypertension, cardiovascular diseases as well as affecting the functionality of the kidney [9].

Chromium is a trace heavy metal which is not always found in surface and ground water. It enters the water bodies mainly by leaching from topsoil and rocks as well as improper disposal of landfills [3, 41]. Chromium has been identified as being highly carcinogenic [22]. Meanwhile, the concentration of chromium in both well and borehole water samples range from 0.01-0.65 mg/L which exceeded the WHO recommended limit (0.05 mg/L). Regular drinking of the well or borehole water poses a serious health risk to the residents of Rumuagholu and Mgbuoshimini community. According to Chika and Prince [3], drinking water that contain chromium above the limit stipulated by WHO will cause human cancer as well as allergic dermatitis.

Copper is not particularly toxic to humans since it is an essential dietary requirement. It possess anti-oxidative properties, plays a vital role in the development of the brain, formation of foetus, transmission of neuron message and help build the immune system. However, at a very high concentration, copper becomes associated with some diseases and ailments. They include kidney diseases, stomach cramps and damage to the liver [10]. One of the problems associated with high level of copper ions in water is galvanic corrosion of tanks (EPA, 2001). It damages paper, fabric as well as responsible for corrosion of the inner walls of high-pressure boilers [3]. Leaching of copper from pipes contaminate drinking water as well as leave a blue-green stain on a bath [24]. The results obtained from this study shows that the concentration of copper ions in both well and borehole water samples is within the range of 2.53-7.07 mg/L. Based on the limit set by WHO which is 2 mg/L, the values reported in this study exceeded it. In a related study, Okonkwo *et al.* [32] and Akpoveta *et al.* [40] reported lower values compared with our result. According to Chika and Prince [3], gastrointestinal disorder could arise if human beings drink water containing copper ions that exceed the WHO limit.



Iron ( $\text{Fe}^{2+}$ ) exist in significant amounts in soils and rocks, principally in insoluble forms. It occur naturally in ground formations which can give rise to more soluble forms. Considerable amounts of iron could be present in ground waters. The characteristic red colour of blood is due to iron. Haem protein synthesis takes place if iron is present. Notably is the role of iron in a genetic and metabolic disease condition which requires patients to undergo repeated blood transfusion [10]. Although iron does not cause any serious harm to human health, excess amount of it could cause damage to paper, fabric as well as responsible for corrosion of the inner walls of high pressure boilers [3]. Excess iron content in water turns the colour to brown. When it is exposed to air, the iron present in the water is converted to Fe (III) which impacts the colour [10]. Laundry materials becomes stained if water with excessive iron is used for washing likewise vegetables which becomes discoloured when it is used for cooking. Problem of taste in meals might occur as a result of using water with high content of iron to cook [42]. The concentration of iron in the water samples obtained from the wells and boreholes in the two communities were within the range of 0.15-6.03 mg/L. The values exceeded 0.3 mg/L which is the limit set by WHO. However, the values reported by Okonkwo *et al.* [32] were lower than what was obtainable in this study.

Lead (Pb) is one of the most commonly determined heavy metals because it is toxic and accumulate in the body tissue. Sources of lead contamination of surface and ground water are leaded gasoline, mining activities, municipal wastes, paint residue, plumbing, burning of coal, etc. Lead affects human health by causing kidney diseases, anemia, cancer, and interference with vitamin D metabolism. Also, it is toxic to the central and peripheral nervous systems and retards mental development in babies [3, 42]. Results from this study shows that the amount of lead in the water samples from the wells were within the range of 21.33-30.16 mg/L is higher than the values reported for borehole water samples (10.34-19.82 mg/L). This result is worrisome because it exceeded the limit set by WHO which is 0.01 mg/L.

The concentration of  $\text{Mg}^{2+}$  which could be toxic at high concentration in the environment is influenced by human activities. The distribution of this useful metal in natural water is not uniform. Dolomite in sedimentary rocks, serpentines and tremolites in metamorphic rock are the various sources of magnesium ions in the hydrosphere. Results obtained from this study shows that the level of  $\text{Mg}^{2+}$  in the water samples from the wells and boreholes were within the range of 0.42-3.00 mg/L. High concentration of  $\text{Mg}^{2+}$  in water causes hardness, as well as exert a cathartic and diuretic action. Interestingly, the concentration of  $\text{Mg}^{2+}$  in the water samples from the wells and boreholes were within the WHO limit of 20-125 mg/L [3].

Zinc is one of the trace elements the body needs in minute quantity. It is popularly known to boost the immune system. However, excess quantity of it causes diarrhoea in humans [10]. Zinc salts that are highly soluble are many. The range of zinc concentration in the well and borehole water samples is 2.08-6.50 mg/L. Water samples (MBBO, MBBO2, RMBO2 and RMBO3) from the boreholes and well (RMWE3) were within the limit set by WHO which is 3 mg/L, whereas other water samples exceeded the limit. High concentration of Zn in the human body leads to accumulation of this trace element. Zinc does not cause cancer in human. That notwithstanding, when it is consumed in excess, zinc could cause dehydration, vomiting, lethargy, abdominal pain and dizziness [3].

Bromide is corrosive to human tissue in a liquid state and its vapour are very toxic when it is inhaled. It is also slightly soluble in water. The concentration of bromine in water samples from the wells and boreholes located in both communities were 0.02 mg/L and 0.01 mg/L, respectively. Both results is within the WHO limit which is 0.1 mg/L.

Chloride is one of the most important anions found in water. It is useful in maintaining acid-base balances. However, when it becomes excess in drinking water, it might cause edema. The source of contamination of water by chloride is sewage and industrial effluents as well as saline intrusion. The chloride content of both well and borehole water examples were within the range of 0.38-1.34 mg/L. Based on the recommended quantity of chloride in drinking by WHO not exceeding 250 mg/L, the values obtained in this study were within the limit. This result is in agreement with a similar study carried out by Alex *et al.* [23] which reported chloride content between 3.28-34.5 mg/L in groundwater samples in a community in Rivers state. If the concentration of chloride in water exceed the WHO limit, the water is bound to have taste which is not a characteristic of pure water.

Phosphorus occurs commonly in plants, microorganisms, and animal wastes. It is mostly used as an agricultural fertilizer and as a major constituent of detergents, particularly those for domestic use. Run-



off and sewage discharges are thus important contributors of phosphorus to surface waters [42]. The result obtained from this study shows that concentration of phosphate in well and borehole water samples is within the range of 0.28-0.58 mg/L. The values reported in this study were within the recommended limit by WHO which is 0.5 mg/L except water sample MBBO3, MBWE1 and MBWE2. Meanwhile, Oko *et al.* [43] reported values from a related study which is above what was obtained in this study.

Sulphate exist in almost all natural waters. Its concentration varies depending on the nature of the environment through which they flow. The usefulness of water for domestic purposes could be affected by high concentration of sulphate. The concentration of sulphate in well and borehole water samples were within the range of 33.11-108.56 mg/L which were below the limit (250-500 mg/L) recommended by WHO. Therefore, the sulphate concentrations in all the water samples were indications of good water quality. One of the problems associated with polluted water containing sulphate in excess quantity is to attack the fabric of concrete sewer pipes [42]. In a related study, Ugbaja and Otokunfor [5] reported lower values for sulphate concentration in groundwater samples obtained from a community in Rivers state which is within the range of 0.43-14.8 mg/L.

Nitrate is the most oxidized form of nitrogen compounds. It is generally found in surface and ground water because it is the end product of aerobic breakdown of organic nitrogenous matter [44]. Farm fertilizer that is used to boost crop yield contains nitrate which is a major ingredient. In areas where latrines and septic tanks are not well sited, nitrate can leak from it and contaminate shallow groundwater. Organic waste emanating from fish, birds and livestock can as well contaminate groundwater. The nitrate is not a direct toxicant but could cause health hazard when converted to nitrite. Our result shows that the nitrate content of the well and borehole water is within the range of 1.06-1.94 mg/L which is within the limit (10 mg/L) recommended by WHO. A similar finding was reported by Ugbaja and Otokunfor [5] and Alex *et al.* [23] from a study that involved quality assessment of groundwater in some communities in Port Harcourt. Children could experience methamoglobinaemia if they consume drinking water containing nitrate exceeding 44 mg/L [23].

## **5. CONCLUSION**

This study has shown that the pH, dissolved oxygen, and turbidity of water from three (3) wells and three (3) boreholes located in Rumuagholu and Mgbuoshimini community were above the recommended limits by World Health Organization (WHO). In contrast, the temperature, electrical conductivity, total dissolved solid, total suspended solids, total hardness and salinity of the water were within the WHO limit. Also, the total alkalinity of the well and borehole water were within the WHO limit except MBWE1 and MBWE2 representing wells located in Mgbuoshimini community. In terms of heavy and non-heavy metals content of water from the same boreholes and wells located in both communities, the cadmium, chromium, copper, and lead content were above the limits recommended by WHO, whereas the magnesium, bromide, chloride, sulphate, and nitrate content were within the limit. Meanwhile, the zinc, iron and phosphate concentration in the water were within the WHO limit with some exceptions. The results from this study indicate that water from the boreholes is fairly better than water from the wells especially in Rumuagholu community. Although the quality of water from Rumuagholu community is relatively better than what was obtainable in Mgbuoshimini community, the overall result from this study indicate that water from the wells and boreholes located in both communities were heavily contaminated and requires further purification process to prevent imminent water-related diseases befallen the residents which could lead to death.

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