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Research Paper

Hydrogeochemical Characteristics and Quality Assessment of Groundwater in Oro-Igwe Communities, Rivers State, Nigeria

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ABSTRACT: *In order to assess the quality of borehole water in Oro-Igwe Communities in Rivers State, the study aims at evaluating the physicochemical and microbial content of the groundwater. Five strategic points were selected from Rumuewhara, Eliozu, Rumuduru and Elimgbu communities for four months (March, April, May and July). Instrumental and classical methods of analyses were employed to measure the parameters of interest. The mean levels of the physicochemical parameters revealed that pH of 5.20±0.16, Temperature of* $28.15^{\pm}$ 0.03^{0}*C, Turbidity, conductivity, salinity and TDS were with mean of* $0.37^{\pm}0.18$ *NTU, 58.81±46.76µS/cm, 0.03±0.02% and 41.46±32.57mg/l respectively. Hardness varied from one location to another with the highest value of 14.3mg/l at EZ1 and lowest value at 0.2mg/l EZ3. Fecal Coliform Bacteria, Total Coliform Bacteria and Total Heterotrophic Bacteria counts did not exceeded the recommended limit of WHO at station EZ1. The water quality index showed that the groundwater in the area is within safe range and will require continuous monitoring.*

Keyword: *Hydrogeochemical, Groundwater, Oro-Igwe, Water Quality, Irrigation indices*

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I. INTRODUCTION

Water is known to be one of the most abundant natural resources in existence that covers about 70.9% of the earth surface and a major constituent of the human body with a chemical formula (H_2O), the two hydrogens and one oxygen are held together by a covalent bond. It has some unique chemical properties such as polarity and hydrogen bond which makes it capable of dissolving, absorbing, and adsorbing or suspend many different compounds.

It is necessary for good health, vitality and longevity. Hence, humans depend on it for their survival and growth. If the body loses more than 2% water supply, it could trigger signals of dehydration, fuzzy and short-term memory. Water aids in the transportation of vital blood plasma, regulates body temperature and provides the basis for the fluid and metabolism. It serves as lubricant in digestion; it also lubricates joints and cartilages and makes them move freely [1].

It is generally obtained from two principal natural sources; surface water such as rivers, streams, ocean, fresh water lakes etc and groundwater such as boreholes and hand-dug wells [2].

The quality of water sources is of a vital concern to man, since it is directly significant to human welfare, a major environmental concern due to controlled and uncontrolled disposal of waste generated by industrial effluents, agricultural and fertilizer runoffs and other human activities [3].

In view of its importance, occurrence and distribution pattern, water is not easily available to man in desirable quality and quantity and this has been a major problem experienced in various cities and towns of developing nations and even in the developed nations such as United States of America where there have been reported cases of diseases such as typhoid fever and cholera [4]. However, access to potable water is an important factor that ought to be considered for improved good health, longevity, sustainable development and increased food production. As a universal solvent, water is essential for various purposes such as domestic chores, industrial processes, agricultural activities and waste disposal [5].

Groundwater whose two sources are boreholes and hand-dug wells have been one of the purest forms of drinkable water in the developed and developing nations, because of the general believe that it is uncontaminated, but presently, due to differences in land use, changes in life style manifested by low level of hygiene practiced in developing nations, most groundwater have been discovered to be primary reservoirs of various pollutants and therefore possess a threat to humans and other living organism.

Groundwater pollution emanates from different sources such as insanitary conditions during borehole drilling, splashing of runoffs into wells, leachate from old burrow pit or latrines, advancement in technology, growing human population, industrialization, oil exploration and exploitation [6].

Heavy metals are metallic elements with relatively high density and atomic weights between 63.546 and 200.590 and a specific gravity greater than 4.0 [2]. They exist as natural constituents of the earth crust and are persistent environmental contaminants because they cannot be degraded or destroyed. However, their concentrations have been highly increased by the activities of man, hence making them toxic or poisonous at high concentrations, examples include Mercury (Hg), lead (Pb), cadmium (Cd), Arsenic (As) and Chromium (Cr) amongst others. They can cause different health problems depending on their nature and quantity.

The aim of this study is to evaluate the hydrogeochemical characteristics and quality of groundwater in Oro-Igwe communities in Rivers State.

II. MATERIALS AND METHODS

2.1 Study Area

Oro-Igwe is located in Obio/Akpor Local Government Area of Rivers State. It comprises of four different communities according to this hierarchy, Rumuewhara, Eliozu, Rumunduru and Elimgbu with different human activities such as farming, trading and diverse commercial activities. The vegetation comprises of thick mangrove forest with tropical monsoon climate and rainfall occurring all through the year except in the late weeks of November and December, which are not completely free from rainfall in some years. The total land area is about 6,032km and a population of about 464,789. It is located between latitude 4^{0}.45N and 4^{0}60N and longitudes 6^{0}50E and 8^{0}00E.

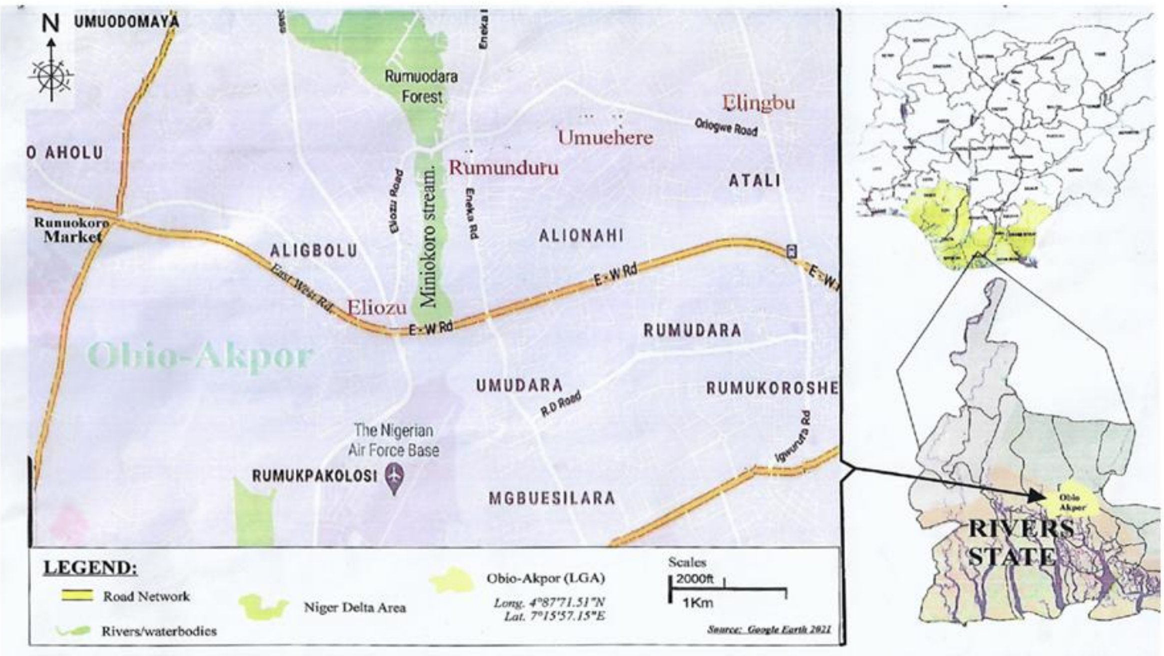


Fig. 1: Map of Rivers State showing the Study Area

2.2 Collection and Preparation of Samples

Samples for physicochemical analysis were collected in 1 litre jerry cans. Before collecting the samples, the jerry cans were properly and thoroughly rinsed with clean water and distilled water and the sample water. For microbial and metal analysis, samples were collected in sterilized vials.

All samples were carefully labeled according to the chosen strategic points of collection and communities of interest. Samples for microbial contents and heavy metals were transported in an ice-box to the laboratory and stored in refrigerator at 4^0C until analysis. Field measurement of pH and temperature were performed using a multimeter (CRISON MM40, Barcelona Spain).

2.3 Analytical Methods

The laboratory methods suggested by the American Public Health Association [7] were used. Conductivity was measured with a probe and a meter that applies a voltage between two electrodes. When the electrodes are submersed in water, the drop in voltage was calculated for conductivity. The drop is due to the resistance in voltage from charged ions in water.

Nitrate was determined using Brucine method, sulphate was determined by turbidimetric method, phosphate was determined using Stannous chloride method, chloride was determined by the Argentometric method, dissolved oxygen (DO) and Biological Oxygen Demand (BOD) were determined by the Winkler's method, calcium was determined by the EDTA titration method and Ammonia was determined by phenate method.

2.4 Heavy Metals

The metals of interest were analyzed using Atomic Absorption Spectrophotometer (AAS). The sample was aspirated into a flame where it becomes atomized. A light beam is directed through the flame into a monochromator and then onto a detector that measures the intensity of the light absorbed. The amount of light intensity absorbed in the flame is proportional to the concentration of the element in the sample.

2.5 Microbiological Analysis

Heterotrophic plate count was performed using the pour plate method. An aliquot (0.1) was aseptically transferred into sterile Petri dish and cooled sterile nutrient agar was added. The mixture was allowed to solidify and then incubated at 37^0Cfor 48hrs. Bacterial colonies on each plate was counted and multiplied by the reciprocal of the appropriate dilution.

2.6 Water Quality Index

Water quality index was calculated using the following method:

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} qiwi}{\sum_{i=1}^{n} wi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where:
q_i=quality rating (sub index) of ith water quality parameter
w_i= unit weight of ith water quality parameter; = 1

Also, q_i, which relates the value of the parameter in polluted water to the standard permissible value is obtained as follows:

$$q_i = (C_i / S_i) \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where q_i, C_i, and S_i indicated quality rating scale, concentration of i parameter, and standard value of i parameter, respectively.

Relative weight was calculated by:

$$w_i = 1/S_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Although there are different methods for calculating Water Quality Index, this study adopted the NSF-WQI (National Sanitation Foundation-Water Quality Index) of the United States and includes the following nine parameters of quality: TDS (total of dissolved solids), pH, turbidity, phosphates, nitrates, BOD, Fecal Coliform, OD (dissolved oxygen) and temperature.

WQI-NFS is a numerical value between 0-100; Wi is the weighting factor for each parameter; Qi is the sub-index of the quality parameter i, which is obtained from the conversion curve (curves that convert parameters determined by values from the interval 0-100).

2.7 Water Classification (Piper's Diagram)

The hydrochemical evolution of groundwater is determined by plotting the cations and anions in Piper trilinear diagram [8]. This diagram reveals similarities and differences among water samples [9]. It consists of two lower triangular fields and a central diamond-shaped field. All the three fields have scales reading in % of meq/l. The data points are pointed in two triangles and projected on to the diamond grid. The water quality types can be quickly identified by the location of points in the different zones of the diamond-shaped field.

2.8 Irrigation indices

a) Sodium Adsorption Ratio (SAR) was calculated by the equation given below [10].

$$SAR = \frac{Na^{+}}{\left\{\frac{(Ca^{2+}) + (Mg^{2+}])}{2}\right\}^{1}_{2}}$$

……………………………………………………………………………………..(4)

Where, all the ions are expressed in meq/L.

(b) Soluble sodium percentage (SSP) was calculated by equation [9].

$$SSP = \left[\frac{Na^{+}}{Ca^{2+} + Mg^{2+} + Na^{+}}\right] x100$$

……………………………………………………………………………………

……(5)

Where, all the concentration of $Ca^{+2} + Mg^{+2} + Na^{+}$ are expressed in meq/L.

(c) the residual sodium Bicarbonate (RSBC) was calculated according to [11].

$$RSBC = HCO_3^- - Ca^{2+}$$

……………………………………………………………………………………

…………..(6)

Where, all RSBC and the concentration of the constituents are expressed meq/L.

(d) The Permeability Index (PI) was calculated according to the equation given by [12].

$$PI = Na^{+} + \left(\frac{(\sqrt{HCO_3^-})}{Ca^{2+} + Mg^{2+} + Na^{+}}\right) x\,100$$

……………………………………………………………

……(7)

Where, all the ions are expressed in meq/L.

(e) Magnesium Adsorption Ratio (MAR) was calculated by the equation given by [13].

$$MAR = \frac{Mg^{2+} x\ 100}{Ca^{2+} + Mg^{2+}}$$

……………………………………………………………………………………

………(8)

Where, all the ionic concentrations are expressed in meq/L.

(f) The Kelly's Ratio was calculated using the equation by [14]

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}}$$

……………………………………………………………………………………

…………(9)

Where, all the ionic concentrations are expressed in meq/L.

IV. RESULTS

4.1 Physicochemical Parameters

The results for the levels of physicochemical parameters of groundwater at the study areas are shown in Figs 4.1 – 4.20. The pH levels ranged from 4.3 – 6.2; temperature ranged from 28.1 – 28.2; turbidity ranged from 0.2 – 0.95 NTU; conductivity ranged from 15.25 – 221.0 µS/cm; salinity ranged from 0.01 – 0.11%; TDS levels ranged from 10.75 – 154.5 mg/l; Hardness ranged from 0.0 – 7.825 mg/l; Alk ranged from 5.0 – 10.5 mg/l; chloride levels ranged from 0.25 – 14.23 mg/l; sulphate ranged from 1.0 – 4.65 mg/l; nitrate ranged from 0.15 – 2.47 mg/l; phosphate ranged from 0.09 – 5.90 mg/l; manganese ranged from 0.005 – 0.101 mg/l; calcium ranged from 0.018 – 1.53 mg/l; magnesium ranged from 0.063 – 1.323 mg/l; iron ranged from 0.066 – 0.221 mg/l; HCO_3^- ranged from 5.0 – 10.5 mg/l; potassium ranged from 0.047 – 4.190 mg/l; sodium ranged from 0.889 – 34.913 mg/l; THC ranged from 1.485 – 6.270 mg/l; THC level ranged from 1.49 – 6.27 ppm.

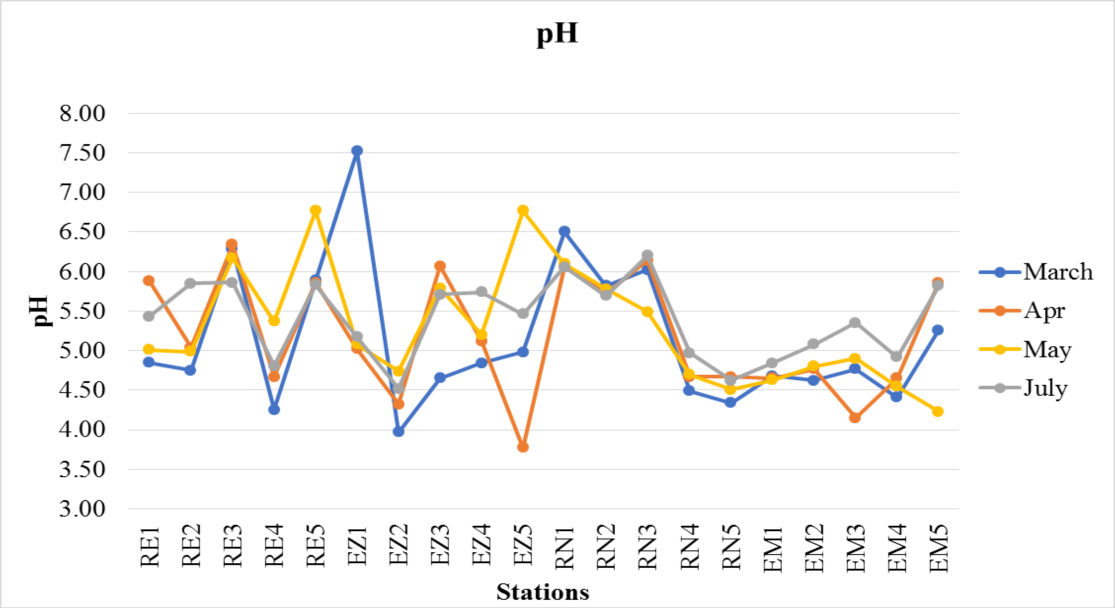


Fig 4.1: Variations in pH of Borehole Water in the Study Area by Months

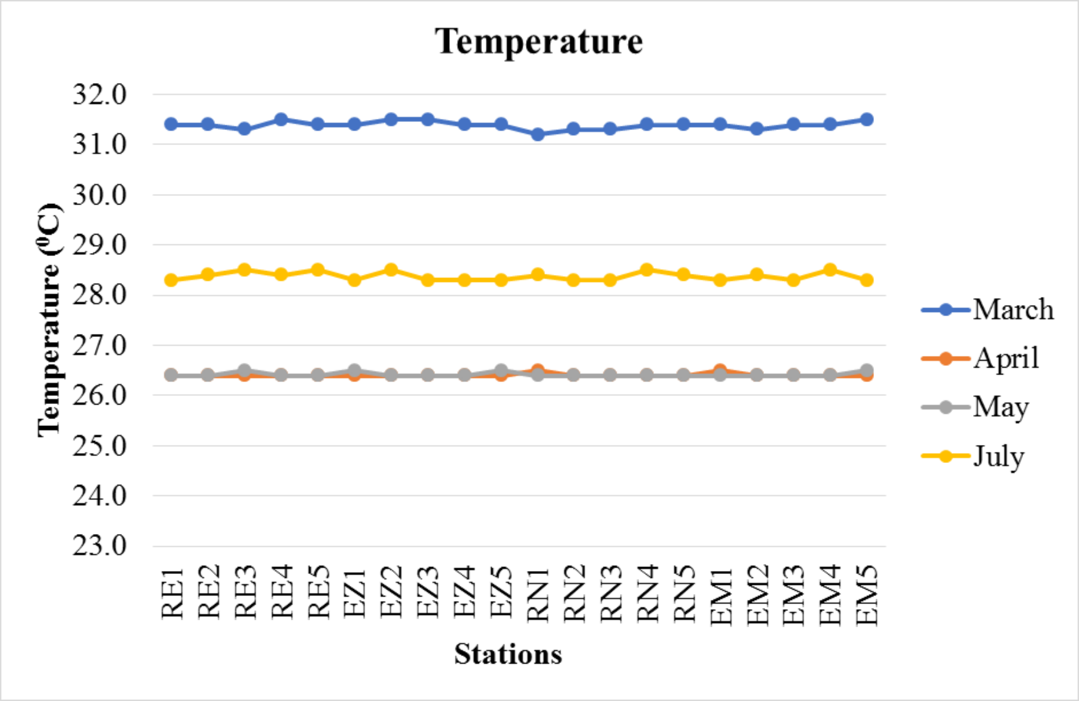


Fig 4.2: Variations in the Temperature of Borehole Water in the Study Area by Months

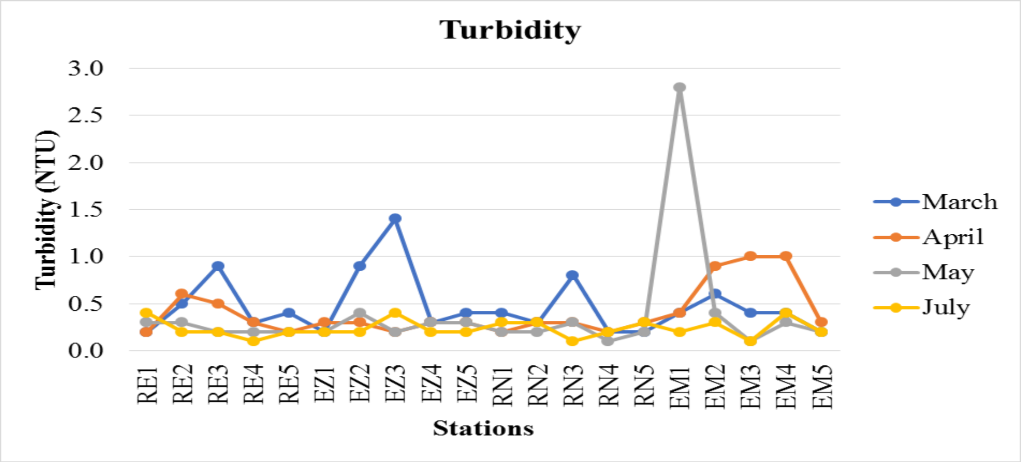


Fig 4.3: Variations in Turbidity of Borehole Water in the Study Area by Months

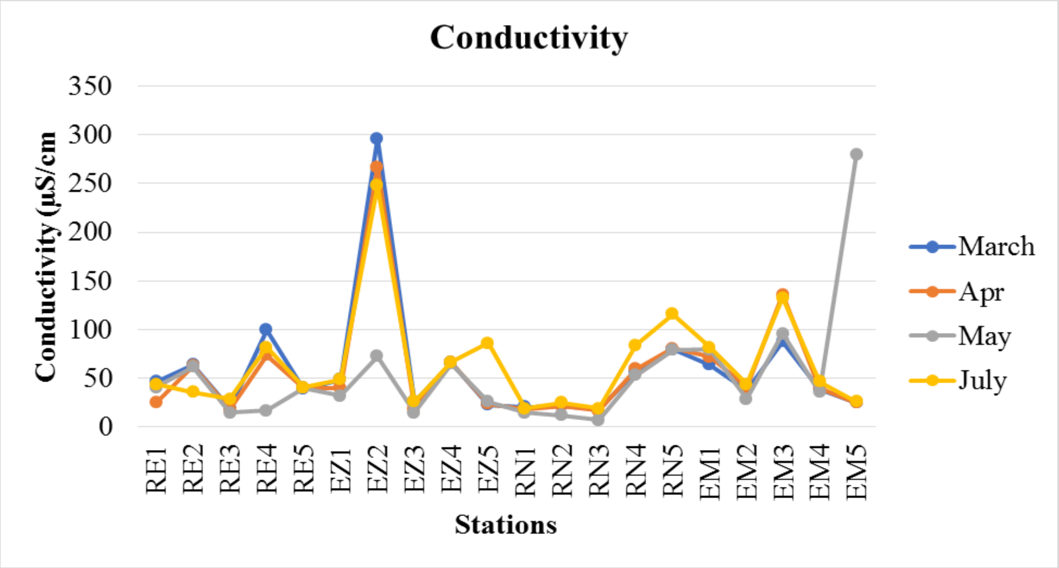


Fig 4.4: Variations in Conductivity of Borehole Water in the Study Area by Months

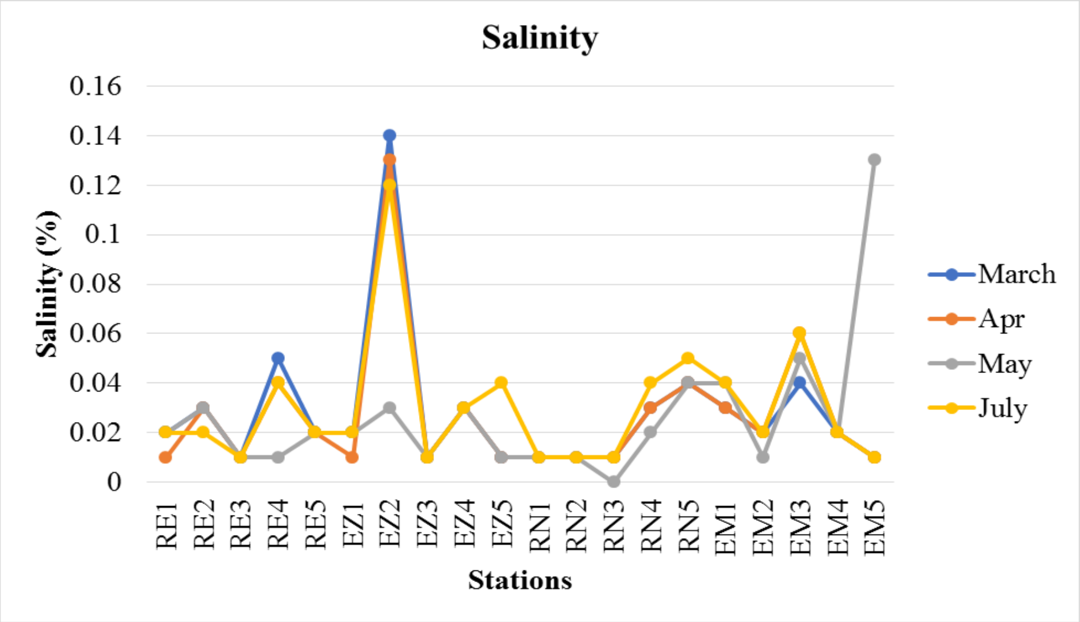


Fig 4.5: Variations in Salinity of Borehole Water in the Study Area by Months

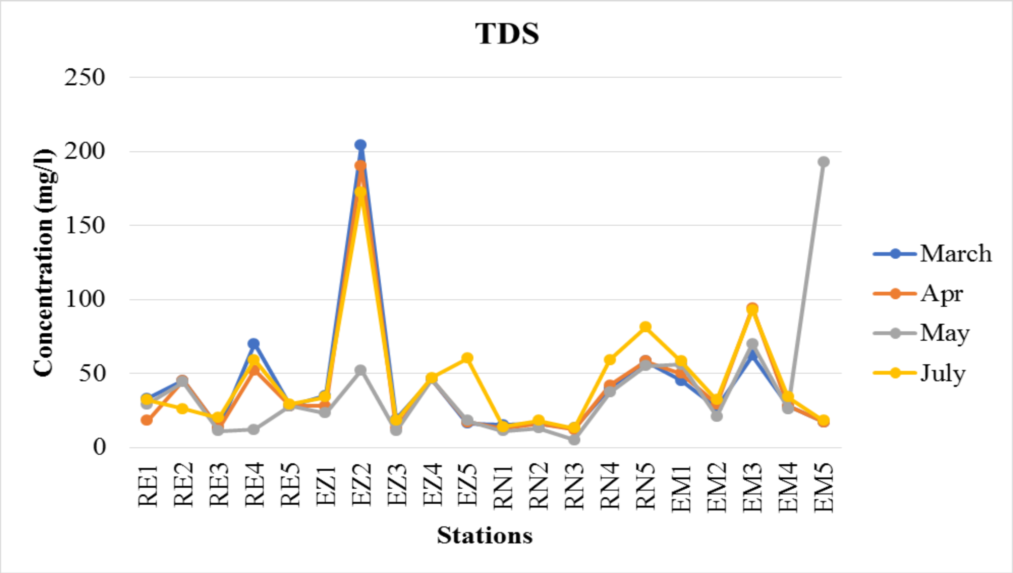


Fig 4.6: Variations in Total Dissolved Solids of Borehole Water in the Study Area by Months

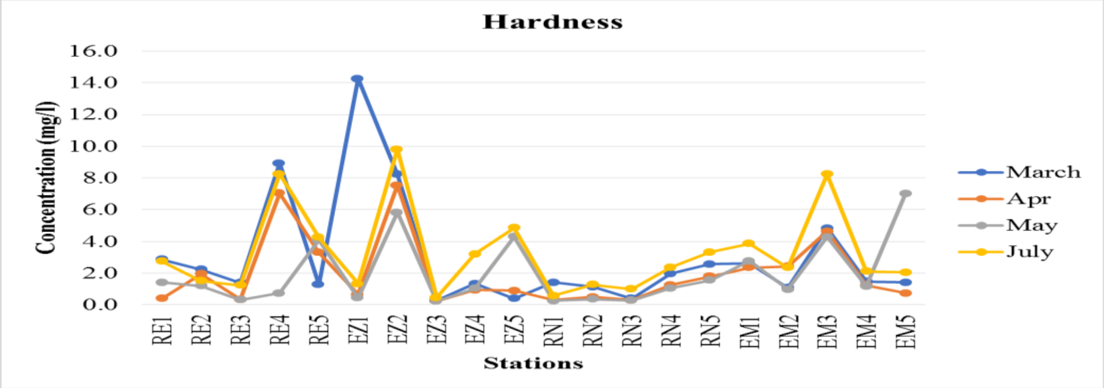


Fig 4.7: Variations in Hardness of Borehole Water in the Study Area by Months

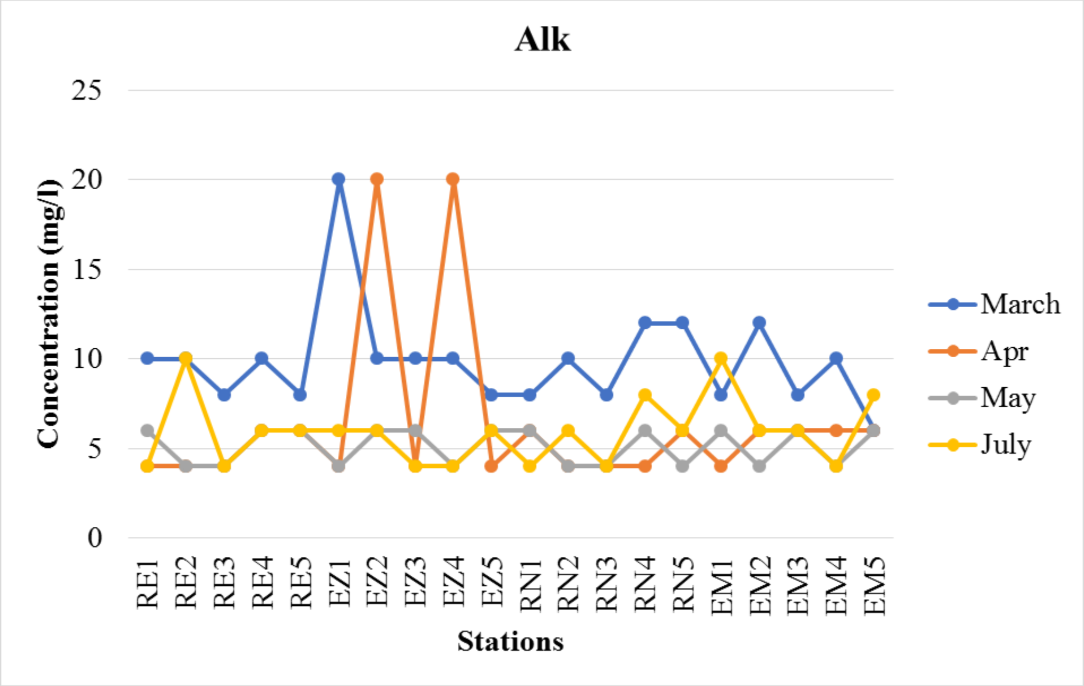
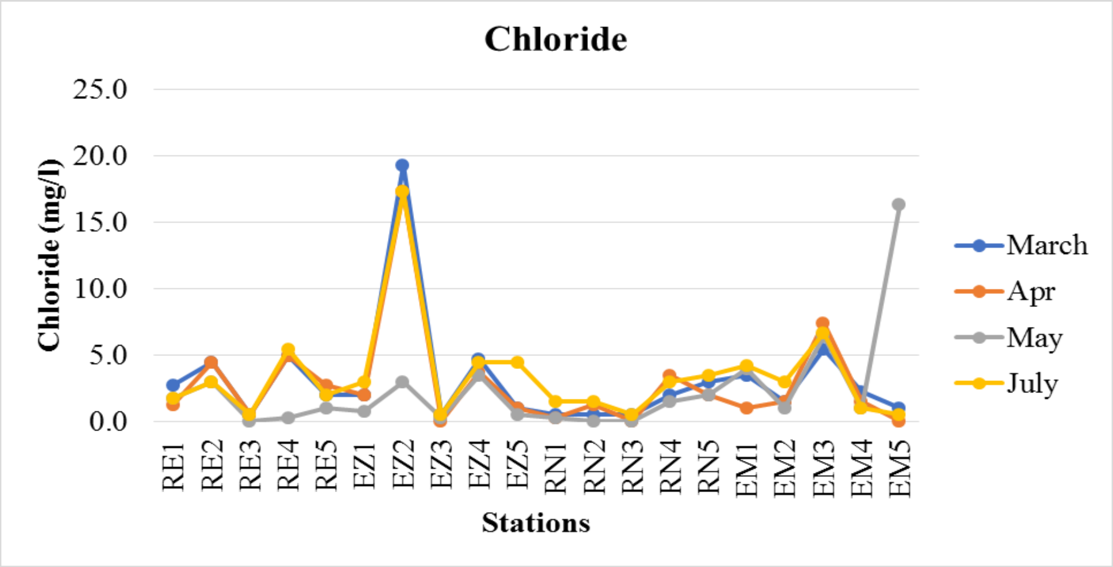


Fig 4.8: Variations in Alkalinity of Borehole Water in the Study Area by Months



4.9: Variations in Chloride levels of Borehole Water at the Study Stations by Months

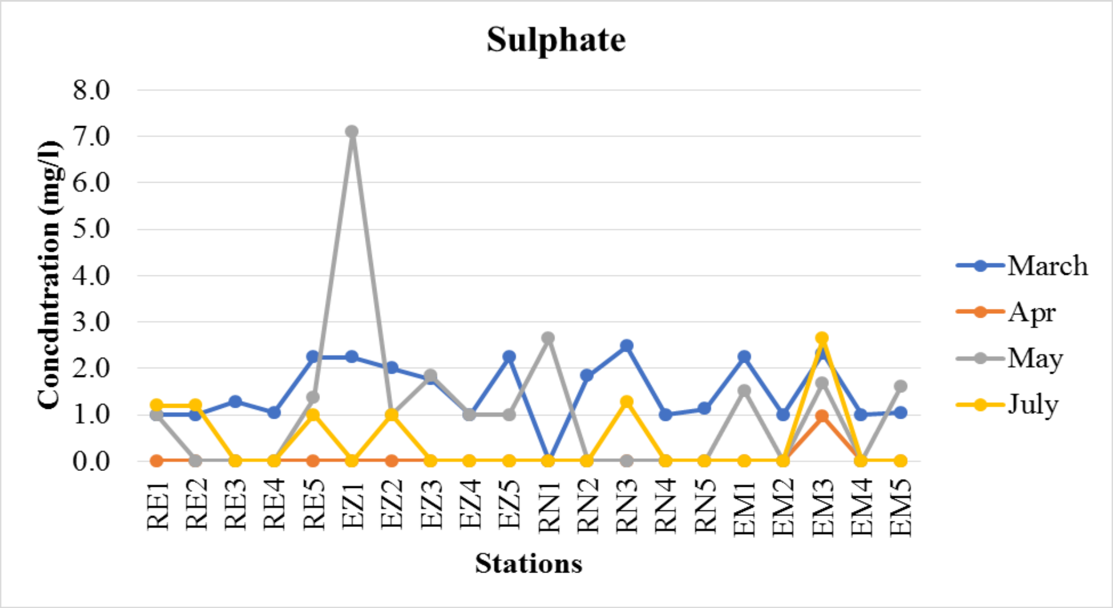


Fig 4.10: Variations in Sulphate Levels of Borehole Water at the Study Area by Months

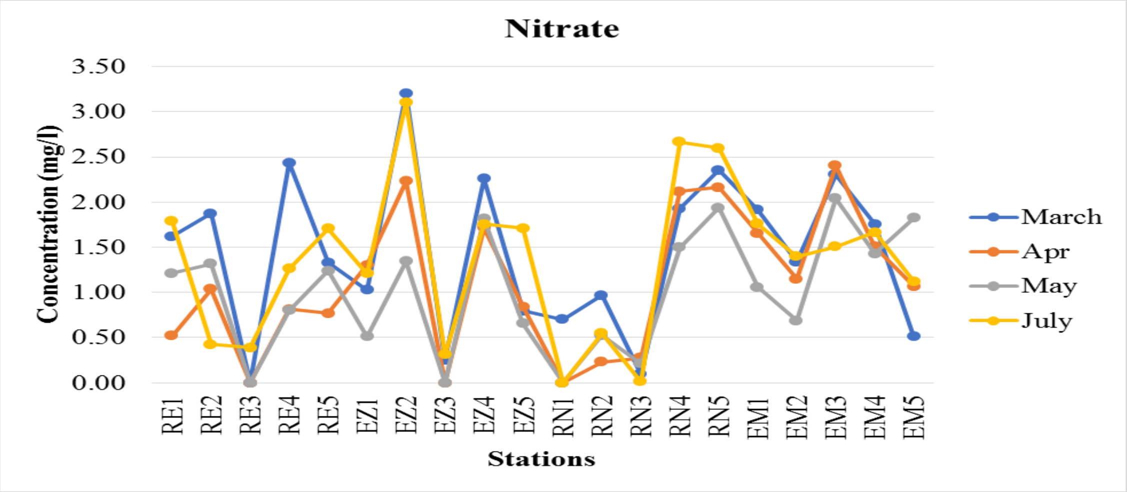


Fig 4.11: Variations in Nitrate Levels of Borehole Water at the Study Area by Months

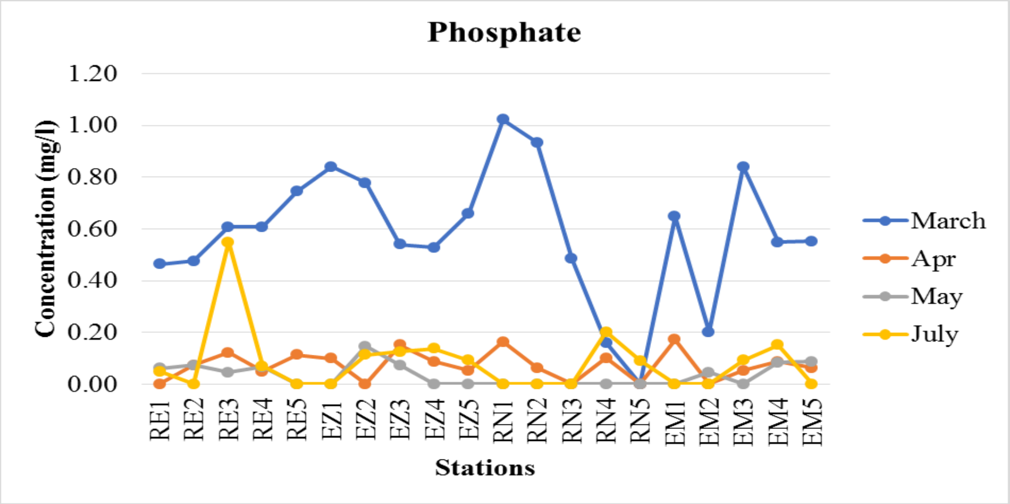


Fig 4.12: Variations in Phosphate Levels of Borehole Water at the Study Area by Months

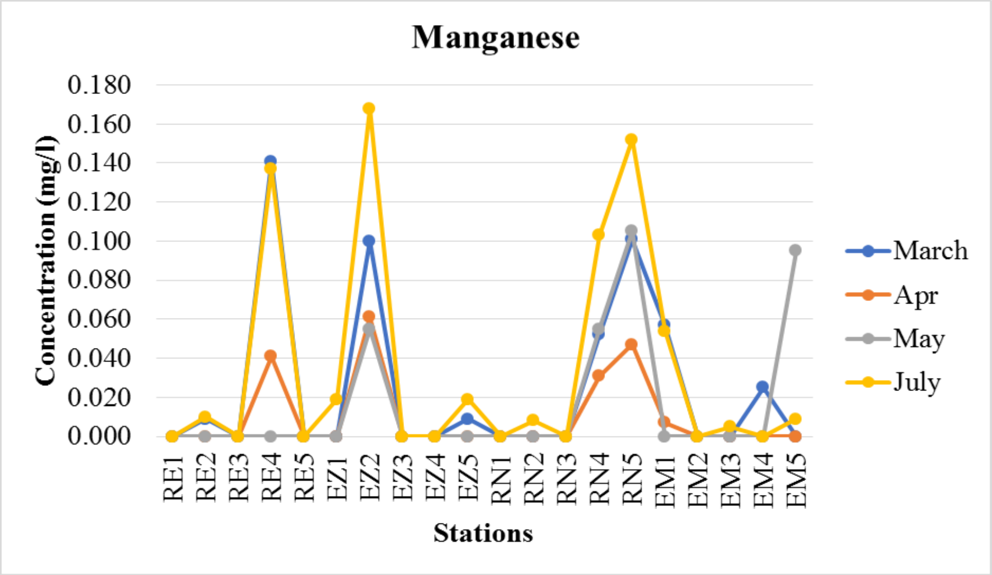


Fig 4.13: Variations in Manganese Levels of Borehole Water at the Study Area by Months

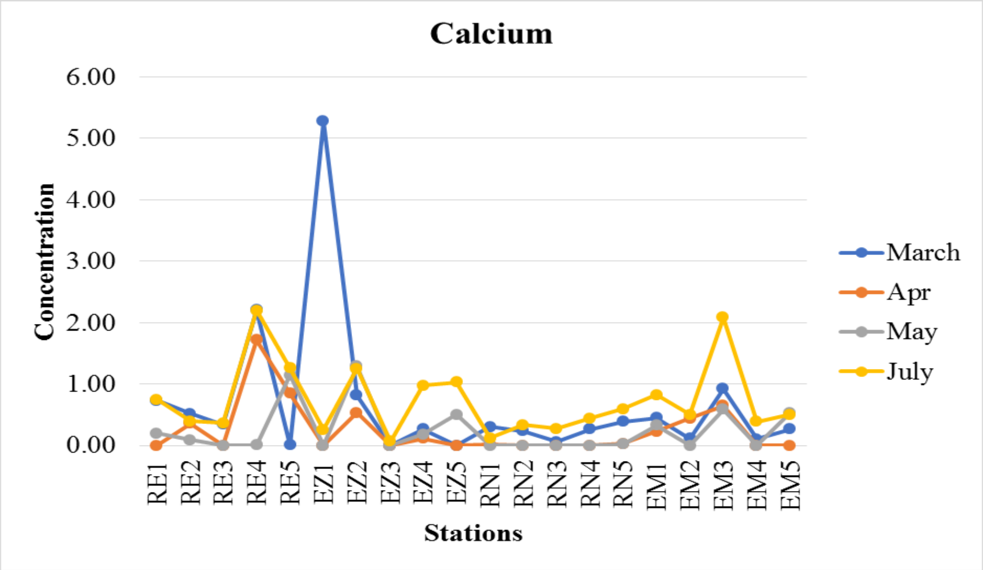


Fig 4.14: Variations in Calcium Levels of Borehole Water at the Study Area by Months

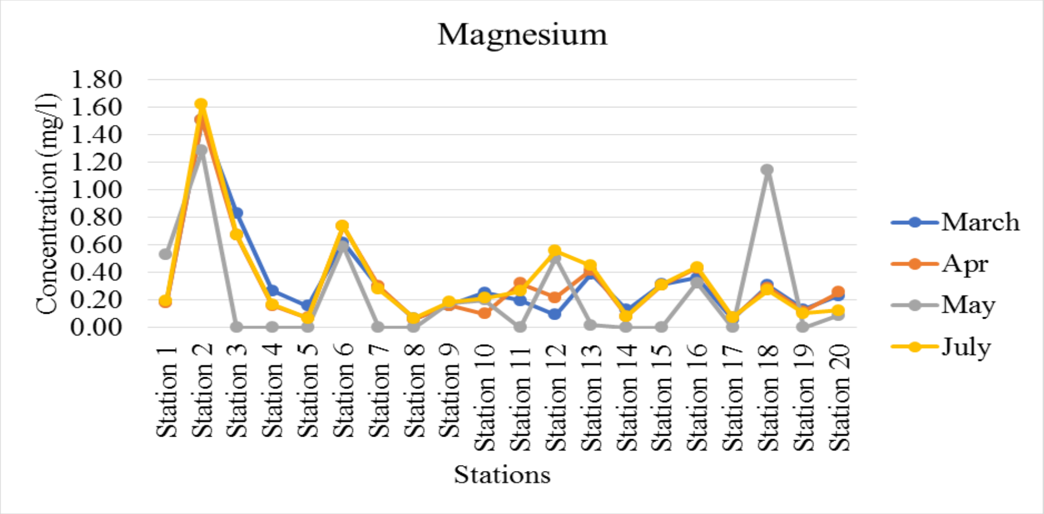


Fig 4.15: Variations in Magnesium Levels of Borehole Water at the Study Area by Months

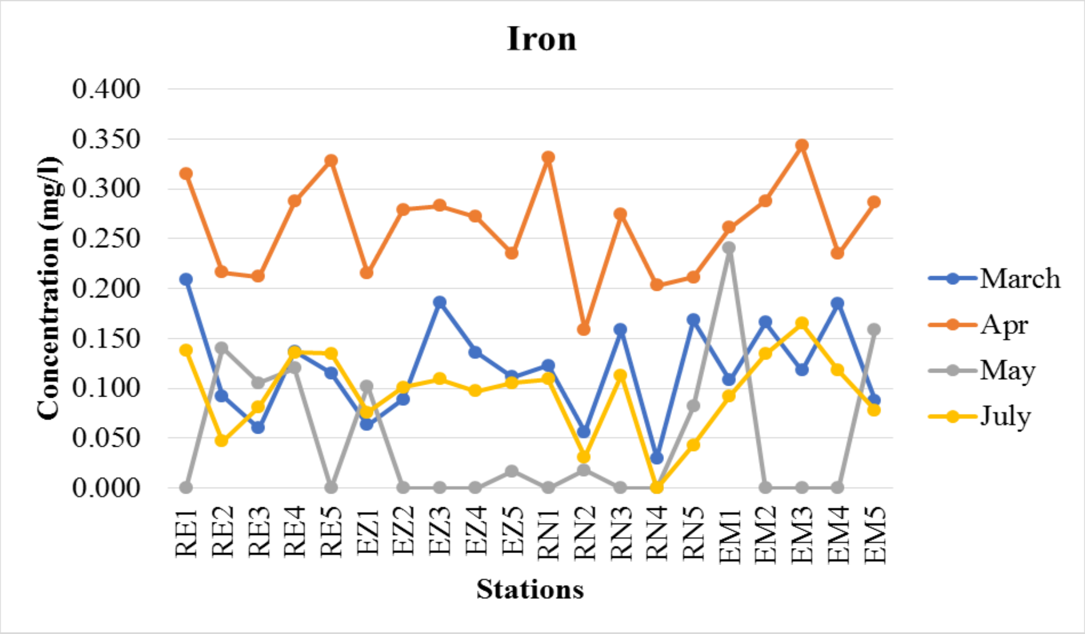


Fig 4.16: Variations in Iron Levels of Borehole Water at the Study Area by Months

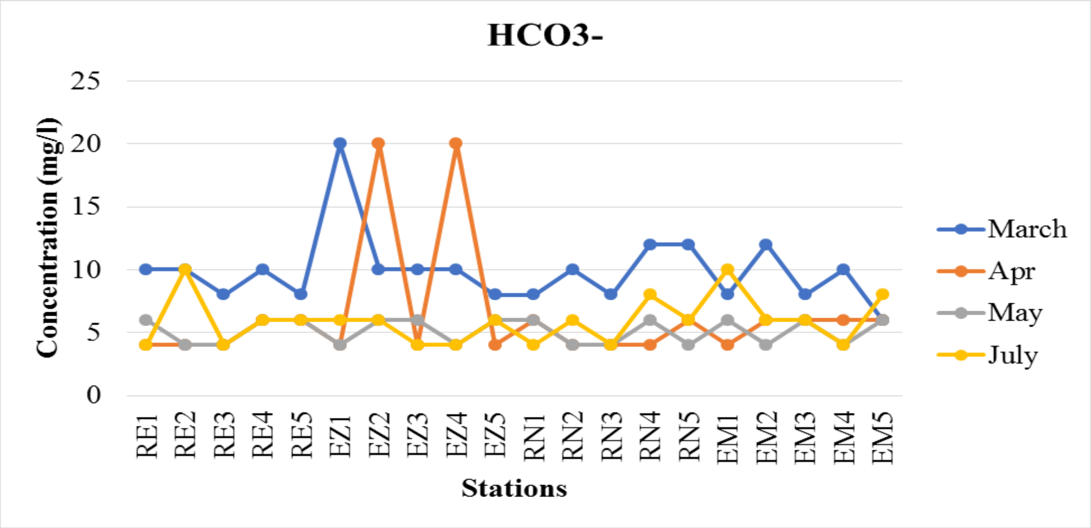


Fig 4.17: Variations in HCO_3^- Levels of Borehole Water at the Study Area by Months

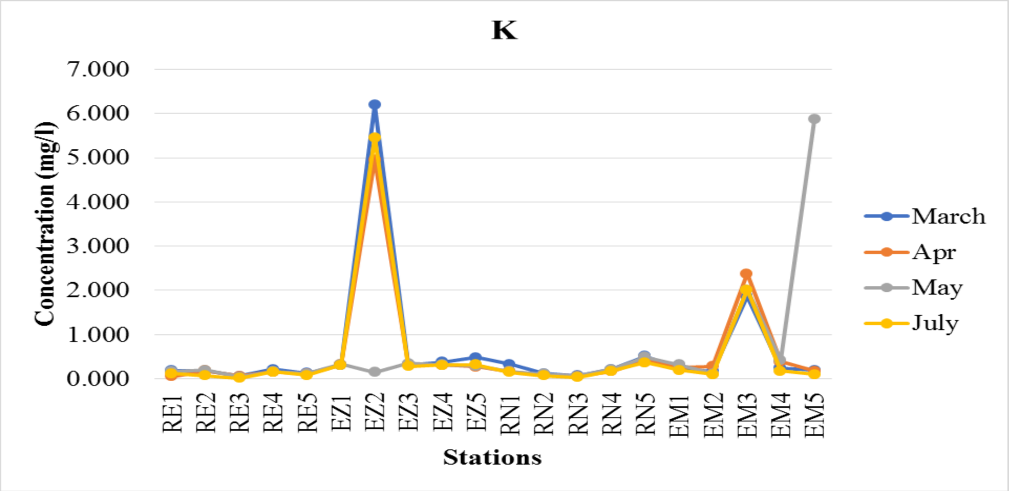


Fig 4.18: Variations in Potassium Levels of Borehole Water at the Study Area by Months

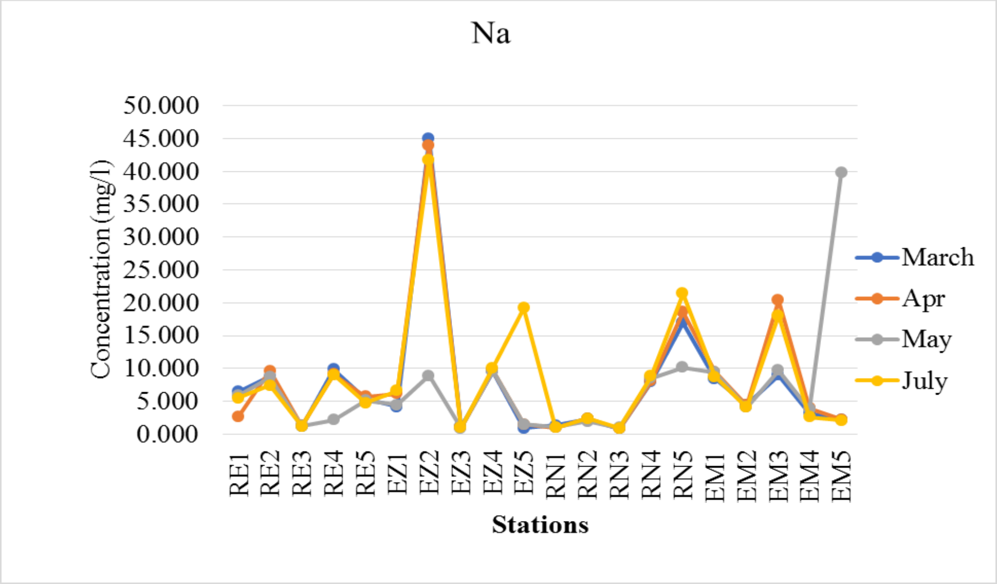


Fig 4.19: Variations in Sodium Levels of Borehole Water at the Study Area by Months

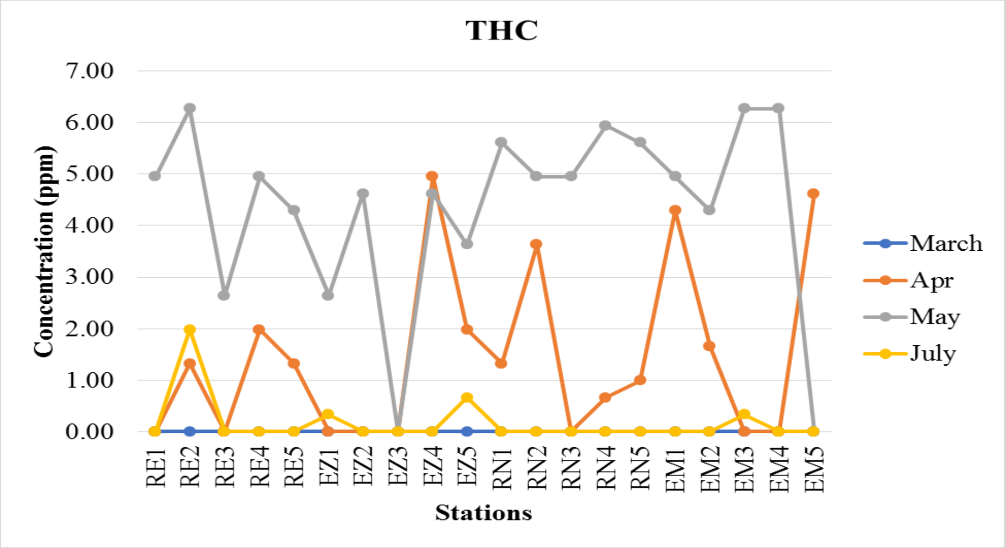


Fig 4.20: Variations in THC Levels of Borehole Water at the Study Area by Months

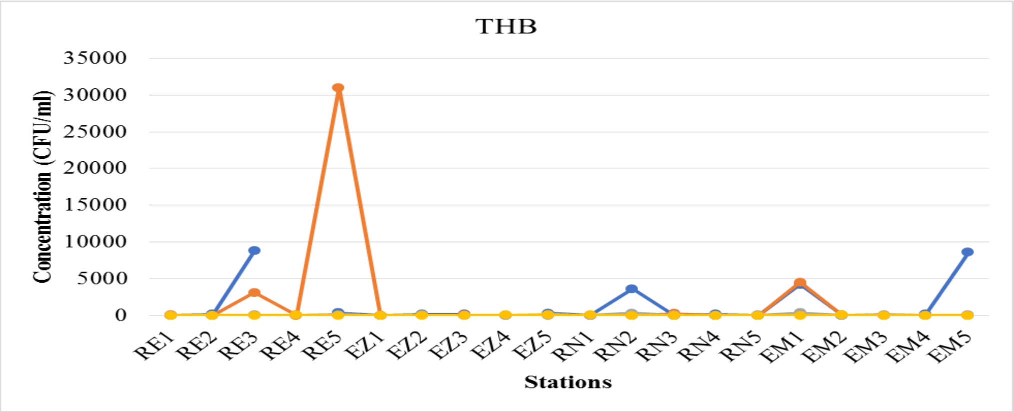


Fig 4.21: Variations in THB Levels of Borehole Water at the Study Area by Months

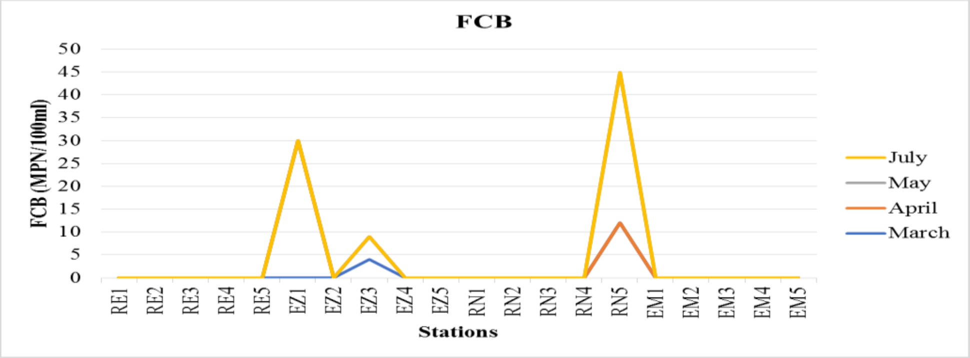


Fig 4.22: Variations in FCB Levels in Borehole Water at the Study Area by Months

4.2 Classification of Water

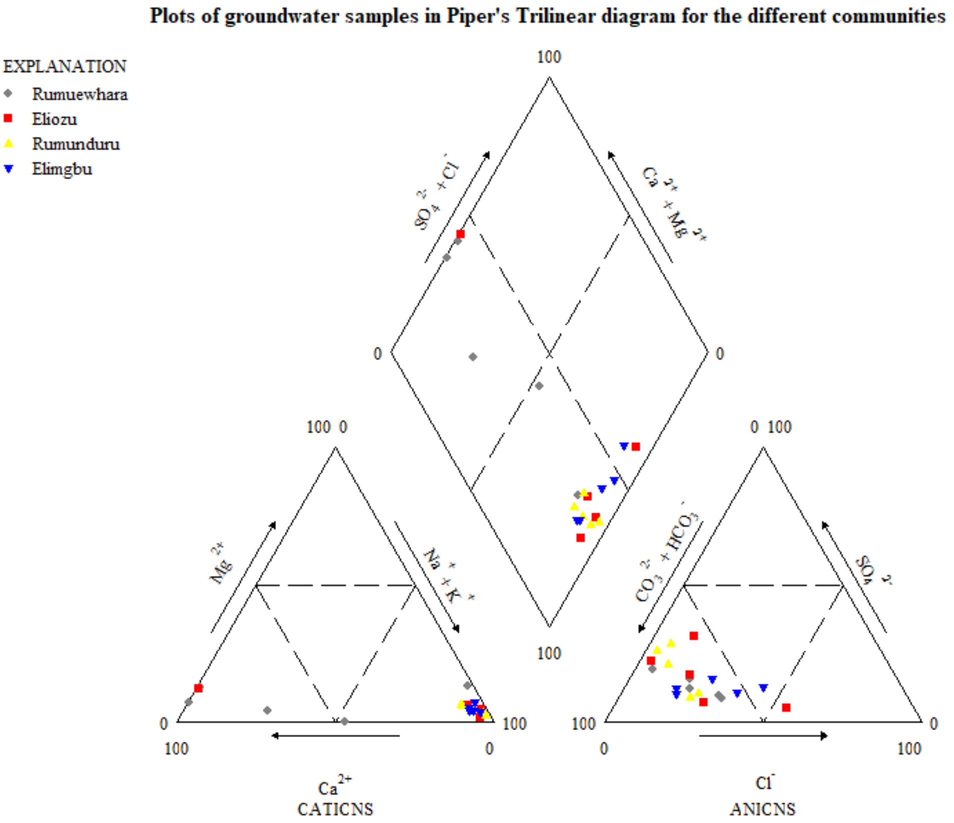


Fig 4.23: Piper trilinear diagram showing groundwater classification at the study area

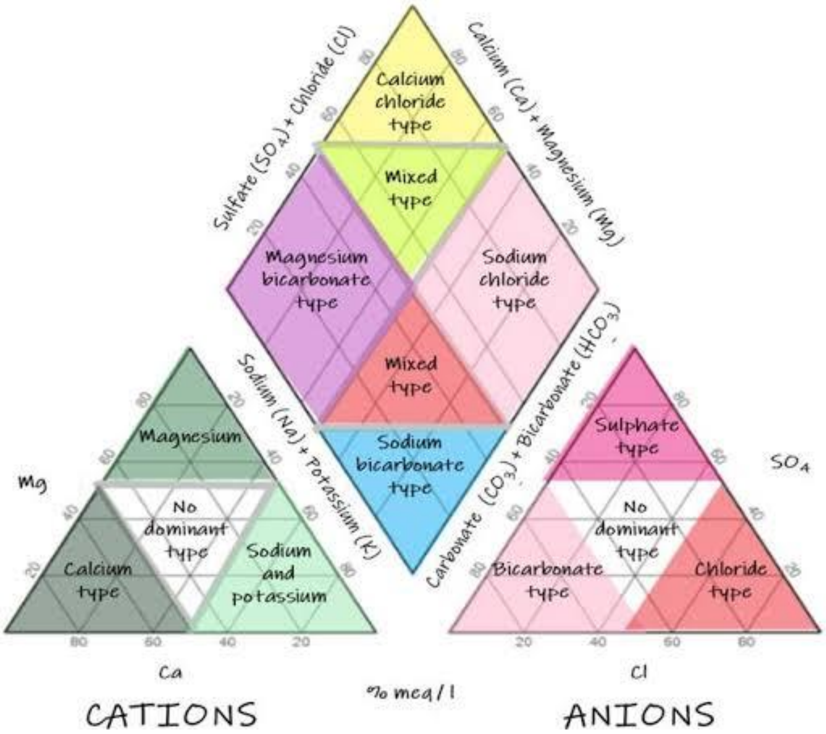


Fig 4.24: Different Regions of the Piper Trilinear Diagram

Table 1: Irrigation Indices of Ground water in the Study Area

Stations	SAR	SSP	RSBC	PI	MAR	KR
RE1	9.21	89.24	5.58	47.88	32.04	8.29
RE2	16.35	93.95	6.66	37.50	38.42	15.54
RE3	3.25	81.59	4.82	154.11	34.54	4.43
RE4	7.32	78.06	5.47	34.93	27.81	3.56
RE5	7.01	82.51	5.69	45.56	26.26	4.72
EZ1	6.04	77.36	7.12	47.64	11.25	3.42
EZ2	32.62	93.84	9.53	43.62	57.57	15.24
EZ3	4.85	92.36	5.98	233.59	78.26	12.08
EZ4	18.62	94.68	9.12	39.69	29.91	17.80
EZ5	9.18	87.99	5.62	43.21	51.23	7.33
RN1	3.42	84.41	5.89	192.45	45.61	5.42
RN2	6.32	89.86	5.86	99.90	43.85	8.87
RN3	3.21	85.31	4.92	215.59	45.75	5.81
RN4	17.17	94.63	7.32	39.35	62.82	17.62
RN5	29.16	96.20	6.74	31.95	61.17	25.33
EM1	13.58	91.08	6.54	35.71	48.38	10.21
EM2	8.38	89.16	6.74	59.50	49.09	8.22
EM3	15.24	89.06	5.44	30.18	39.56	8.14
EM4	7.44	89.11	5.88	67.87	69.89	8.19
EM5	18.19	93.45	6.17	32.15	59.84	14.27

Table 2: Classification of samples according to standards specified for different water quality parameters

Parameter	Range	Class	No. of Samples	Percentage of samples
SAR	<20	Excellent	18	90
	20-40	Good	2	10

	40-60	Permissible		0
	60-80	Doubtful		0
	>80	Unsafe		0
SSP	<200	Suitable	20	100
	>200	Unsuitable		0
RSBC	<5	Safe	2	10
	5.0^{-10}.0	Marginally suitable	18	90
	>10	Unsuitable		0
PI	<80	Good	15	75
	80^{-10}0	Moderate	1	5
	>100	Poor	4	20
MAR	<50	Suitable	13	65
	>50	Unsuitable	7	35
KR	<1.0	Suitable		0
	>1.0	Unsuitable	20	100

Water Quality Index

Table 3: Water Quality Index for the Study Stations

	March	April	May	July
		Rumuewhara		
RE1	56.57	52.68	49.10	52.33
RE2	56.13	64.56	57.64	61.11
RE3	61.68	50.86	61.83	52.79
RE4	54.42	59.28	63.95	49.66
RE5	59.20	65.26	50.65	56.79
		Eliozu		
EZ2	52.05	65.89	58.58	65.11
EZ1	63.70	50.41	60.99	51.90
EZ3	56.32	59.83	56.22	63.56
EZ4	55.99	49.64	63.56	50.20
EZ5	58.43	51.01	50.30	53.54
		Rumunduru		
RN1	61.29	57.12	51.23	64.42
RN2	54.24	50.67	61.49	56.00
RN3	61.05	61.54	59.40	53.11
RN4	57.43	60.11	63.65	50.34
RN5	49.94	51.74	51.45	61.95
		Elimgbu		
EM1	55.43	58.00	58.32	61.00
EM2	57.55	61.74	57.27	60.40
EM3	55.00	59.38	65.01	58.05
EM4	55.19	61.08	53.36	53.73
EM5	57.95	60.35	62.49	57.07

V. DISCUSSION

5.1 Physicochemical Parameters of Groundwater

Groundwater samples in the study area were found to be generally acidic with pH levels ranging from 3.77 at EZ5 to 7.52 at RN1 (Fig 4.1) with mean of 5.20 ± 0.61. The result showed that station and monthly level variations in pH were not significantly different ($p > 0.5$). The safe range for drinking water by FMEnv, USEPA and WHO are 6.5 – 8.5, 5 – 9 and 8.2 – 8.8 respectively [15][16][17]. The mean pH levels of groundwater samples at the study areas were more acidic than the recommended limits for safe drinking water. The low pH of groundwater in the study area may be an indication of chemical activity associated with the decomposition of organic materials into organic acids, or it could be as a result of anthropogenic activities like oil production that leads to pollution in the area[18][19]. It is impossible to establish the relationship between pH of drinking water and human health owing to the fact that pH is so closely associated with other components of the water, and in water, acids and alkalis are normally extremely dilute [16]. However, acidic water with a pH of less than 6.5 is more likely to be contaminated with pollutants, and can lead to the corrosion of metal pipes. The acidity of groundwater reported in this study agreed with previous studies done within the study area and in the Niger Delta at large [18][20][21].

The temperature of water samples in this study ranged between 26.4^0C – 31.5^0C (Fig 4.2) with a mean of 28.15 ± 0.03 ^{0}C. Temperatures of borehole water measured at the study area are not significantly different ($p > 0.05$) from one station to another and from one community to another. The temperature of borehole water measured at different months however showed wide variations: the values in March were significantly higher ($p < 0.05$) than April – July, and the value in July significantly higher ($p < 0.05$) than April and May. The levels in this study are within the ambient temperature guidelines recommended for drinking water [15].

Turbidity, conductivity, salinity and TDS in the groundwater samples were in the range 0.1 – 2.8 NTU with mean of 0.37±0.18 NTU (Fig 4.3); 7 – 296 µS/cm with mean of 58.81±46.76 µS/cm (Fig 4.4); 0 – 0.14% with mean of 0.03 ± 0.02% (Fig 4.5) and 5 – 204 mg/l with mean of 41.46± 32.57 mg/L (Fig 4.6) respectively. There were no significant differences ($p > 0.05$) between the turbidity of the different water samples in the study area as well as between the different months in which observations were made for this parameter. Turbidity measures the degree to which water has lost its transparency due to the presence of suspended particulates. [16] recommended the turbidity of drinking water not exceeding 1.5 NTU while [15] recommended 5 NTU. All the samples were within these limits except EM1 which exceeded WHO limit in the month of May. This suggests the presence of particles in borehole water in this location that may make it unfit for drinking.

The conductivity of the groundwater samples was not significantly different ($p > 0.05$) between the different communities except EZ2 in Eliozu which showed significantly higher ($p < 0.05$) values of conductivity than all other stations. Monthly level variations also showed no significant difference ($p > 0.05$). This parameter at the study area was within 1000 µS/cm limits set by FMEnv for drinking water. Similarly, the salinity and TDS of the groundwater samples were not significantly different except at EZ2 which was significantly higher ($p < 0.05$) than all other stations. Levels of salinity and TDS of groundwater taken in the months of March, April, May and July were not significantly different.

Salinity, conductivity and TDS are related properties and are used to describe the presence of dissolved particles in water. There was very high and significant correlation between the three parameters in this study with $r = 0.995$ (for salinity vs conductivity), $r = 0.996$ (for salinity vs TDS) and $r = 1.00$ (for TDS vs conductivity).

The highest recorded value of total hardness in the groundwater samples was 14.3 mg/l at EZ1, while the lowest value was 0.2 mg/l at EZ3, both at Eliozu. Very wide variations and significantly different ($p < 0.05$) levels in the hardness of borehole water were observed from one community to another. The grouping information revealed that levels of hardness in borehole water at EZ2 and RE4 were significantly higher ($p < 0.05$) than in RN2, RE2, RN1, RN3 and EZ3 and in addition EZ2 recorded levels significantly higher ($p < 0.05$) than RN5, RE1, EM2, RE2, RN4, EZ4 and EM4. The total hardness values of the present study were in agreement with the findings of other studies done in the Niger Delta region of Nigeria [18]. The values in this study were also within the [16] maximum permissible limit of 500 mg/l.

The Chloride ion levels in groundwater samples in the study area were generally low and ranged from 0.00 to 19.30 mg/l. The highest recorded value was at EZ2 and was significantly higher ($p < 0.05$) than all other stations. The chloride levels in the samples were below the maximum permitted limit of 250 mg/l recommended by [22] indicating that its suitability for drinking. The presence of chloride in groundwater may have come from both natural and anthropogenic sources (such as sewage and industrial effluent). The levels found in this study were lower than the levels reported by [20] and [21] but agreed with values reported by [23] and [24].

The highest level of sulphate concentration in the groundwater at the study area was 7.1 mg/l while the least concentration was < 0.1 mg/l. There was no significant difference ($p > 0.05$) in the concentration of sulphate of the groundwater samples, between communities, within the communities and from one month to another. Concentrations of sulphate which exceeded WHO safe limit of 250mg/l implies the water is unsafe for drinking. [25] underscored the problem of high sulphate concentration in water, on account of its combination with calcium or magnesium to produce permanent hardness in water. However, the concentration of sulphate in the groundwater samples from the study area are below the recommended limits and so do not pose any danger for drinking.

Nitrate in the groundwater samples recorded the highest levels of 3.21 mg/l in EZ2 and lowest levels of < 0.05 mg/l at stations 5, 8, 14 and 17. The levels of nitrate recorded at EZ2, RN5, EM3 and RN4 were significantly higher ($p < 0.05$) while RN1, RN2, RE3, EZ3 and RN3 showed significantly lower levels of nitrate. The concentration recorded in the month of March was significantly higher than the concentration observed in the month of May. Exposure to hazardous concentrations of nitrate creates the condition known as methemoglobinemia (blue baby syndrome) in children, a condition in which the ability of the blood to transport oxygen to cells is reduced causing the veins and skin to appear blue [26]. However, WHO and FMEnv tolerance limit of nitrate is 50 mg/l [16] [27]. The concentrations of nitrate in all the groundwater samples were below the recommended limits. The levels observed in this study were also lower than the concentration reported by [20] and [21].

Phosphate concentration in the groundwater samples ranged from <0.05 – 1.02 mg/l. The concentration of phosphate in the samples were not statistically different, however the samples collected in March recorded concentrations of this parameter statistically higher ($p < 0.05$) than other months. Phosphate concentration in this study was lower than the values reported by [28] in their study of nitrate and phosphate pollution in surface water of Nwaja Creek, Port Harcourt. The concentration of phosphate in water may increase due to increasing rates of plant growth and proliferation of planktonic and epiphytic and epibenthic algae, resulting in shading of higher plants [28]. Plants however, do not grow in ground water, hence the low levels of phosphate observed in this study.

At the study area, the highest concentration of manganese in the groundwater samples was 0.141 mg/l in March; 0.047 mg/l in April; 0.105 mg/l in May and 0.168 mg/l in July. For Iron the highest concentrations recorded were 0.21 mg/L for March, 0.34 mg/L for April, 0.24 mg/L for May and 0.17 mg/L for July. Iron and manganese are found in drinking water and have no known health concerns [29] but may cause stains and tastes in water. At concentrations above permissible limits, Iron can also cause an orange or brown stain in the cup. Manganese may result in a dense black stain or solid. [15] recommended limit for Manganese is 0.2 mg/l while the limit for Iron is 0.3 mg/l. The highest concentration was recorded at EZ2 and was below the recommended limit. The highest concentration of Iron was recorded at EM3 and was slightly above the recommended limit. Concentrations of manganese in the samples were not statistically different at the stations and monthly levels. The concentration of Iron was significantly higher in RE1 than in RN2, also the levels observed in April were significantly higher than the levels recorded in March, May and July. The result for Iron level found in groundwater from this study agreed with [20] and [30].

Alkalinity of the ground water at the study area ranged from 4 to 20 mg/L. The values of this parameter in the groundwater samples were below the permissible limit range of 30 to 500 mg/L by [16]. This confirms the acidic nature of groundwater from the study area. Bicarbonate or hydrogen carbonate, is an acid buffer which helps in maintaining the balance of acids and bases in the human body [31]. It ranged from 6 mg/l to 20mg/l in March, 4 mg/l to 20 mg/l in April, 4 mg/l to 8 mg/l in May and from 4 mg/l to 10 mg/l in July.

Sodium concentrations in the groundwater water varied from 0.87 mg/l at EZ5 to 45 mg/L at EZ2 while potassium varied from 0.017 mg/L at RE3 to 6.19 mg/L at EZ2. The concentrations of sodium and potassium in these samples were below the [15] recommended limits of 200 mg/L for both. The results from this study are similar to those reported by [32]. Calcium concentration obtained for the groundwater samples varied from BDL to 5.28 mg/L while magnesium varied from BDL to 1.63 mg/L. The values obtained for both minerals were lower than values reported by [33] in Port Harcourt. Both values obtained are below the recommended limit for drinking water of 200 mg/L and 50 mg/L for calcium and magnesium respectively.

THC concentration in the groundwater ranged from <0.10 to 6.27 ppm at the study area while THB ranged from 0 to 31,000 cfu/ml. THC concentrations in this study were much higher than values reported by [34] which reported a range between 0.010 to 0.254 mg/L in a study at Ikoli Creek, Bayelsa State.

5.2 Classification of Water

The piper trilinear diagram method (Fig 4.24) was used to classify the groundwater, based on basic geochemical characters of the constituent ionic concentrations. The hydrochemical evolution of groundwater is determined by plotting the cations (Na^+/K^+ and Ca^{2+}/Mg^{2+}) and anions (SO_4^{2-}; CO_3^{2-}/HCO_3^- and Cl^-). It was observed from the diagram that about 85% of the groundwater was dominated by the alkalis (Na^+ and K^+) over the alkaline earths (Ca^{2+} and Mg^{2+}) and in 90% of the samples, weak acids (HCO_3^-) exceed strong acids (SO_4^{2-} and Cl^-). The diagram indicates that $Na\text{-}HCO_3^-$ is the major water type dominant in Eliozu, Elimgbu and Rumunduru, while in Rumuewhara community $Mg\text{-}HCO_3^-$ is the dominant water type.

5.3 Irrigation Suitability

The suitability of the groundwater for irrigation purposes was determined using six computed water quality parameters namely (1) Sodium Adsorption Ration (SAR), (2) Soluble Sodium Percentage (SSP), (3) Residual Sodium Bicarbonate (RSBC), (4) Permeability Index (PI), (5) Magnesium Adoption Ratio (MAR) and (6) Kelly's Ration (KR). These indices for each of the 20 sampling locations are shown in table 4.70 while table 4.71 shows the classification of the groundwater samples into different classes.

The result for the SAR of groundwater samples in the study area revealed that 90% were excellent while 10% was good. Two major constituents for determining SAR are total salt concentration and sodium hazard. Water used for the purpose of irrigation requires a balance between Na^+ and Ca^{2+} in order to maintain the ion exchange complex such that excess Na^+ would not destroy the structure of the soil [9]. Soluble Sodium Percentage (SSP) used in assessing the suitability of water for irrigation purposes is important because of the reaction of sodium with soil which may reduce its permeability. The results reveal that 100% of the groundwater samples in the study area were suitable for irrigation with respect to SSP.

RSBC was calculated to determine the hazardous effect of bicarbonate on the quality of water if used for irrigation purposes. It was observed from the result that 90% of the groundwater samples fell into the category of marginally suitable while 10% were safe with respect to RSBC, thus making the groundwater samples from the study area acceptable for irrigation purposes. However, caution should be taken as increased concentrations of HCO_3^- may tip the quality of the groundwater samples over from marginally suitable to unsuitable for irrigation purposes. The hazard of excess $NaHCO_3$ and Na_2CO_3 in water used for irrigation comes from the fact that it may precipitate Ca^{2+} and Mg^{2+} in agricultural soils, thereby impairing the soil and possibly activate soil sodium [35].

Permeability index (PI) is affected by long-term use of irrigation water. Permeability which refers to the capability of water to move in soil is influenced by the long-term use of irrigation water with high salt concentration (such as salts containing Na^+, Ca^{2+}, Mg^{2+} and HCO_3^-). The result indicates good permeability index (PI) for 75% of the ground water samples, moderate PI for 5% and poor PI for 20% of the ground water samples. Water quality ranging from moderate to good PI is recommended for irrigation, therefore, 80% of the water samples in the study area are recommended for irrigation with respect to permeability index.

The result for Magnesium Adsorption Ratio (MAR) revealed that 65% of the groundwater samples is suitable for irrigation while 35% are unsuitable. In most groundwater, alkaline earths (Ca^{2+} and $Mg^{2+)}$ maintain a state of equilibrium. If used for irrigation, however, increased concentration of Mg^{2+} will adversely affect the soil quality by increasing its pH and rendering it alkaline which may also affect crop yield negatively (decrease the availability of phosphorous in soil) [36] [37]. Kelly ratio value greater than 1 (KR>1) indicates an excess level of Na^+ in groundwater. Therefore, water with a KR<1 has been recommended for irrigation, while water with KR>1 is not recommended for irrigation due to alkali hazards [38] [39]. In this study, all the water samples did not pass this criterion and are therefore not suitable for irrigation with respect to Kelly Ratio.

5.4 Water Quality Index

The water quality index of groundwater in the study area ranges from 49.10 at RE1 to 65.89 at EZ2. Most of the WQI values in the study fell within the medium range except in May of RE1, July of RE4, April of EZ4 and March of RN5.

VI. CONCLUSION

The groundwater quality from the communities reveals that pH values were more acidic beyond the safe range for drinking water. Other physicochemical and microbial properties of the groundwater in the study area were within recommended limits, conferring a medium range water quality index for groundwater samples in the study area. The classification of groundwater showed that the dominant water type in the area was Na-HCO_3^- and Mg-HCO_3^-. Groundwater samples in Oro-Igwe were also found to be largely suitable for irrigation purposes. Irrigation indices such as SAR, SSP, RSBC, PI and MAR were found to be mostly within recommended limits while KR was the only irrigation index for which the groundwater fell below the recommended standard at all the locations. There was also no risk of Fe and Mn exposure of the groundwater by means of ingestion of dermal contact in children, while substantial risk of exposure in adults were observed in 6 locations (EM5, EZ2, RE4, RN5, RN4 and EM1).

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