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Application of Water Quality Index for Groundwater Quality Monitoring and Management in Kingsley Ozumba Mbadiwe University Ideato and Environs

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Abstract— *This study was an evaluation of the groundwater quality in Kingsley Ozumba Mbadiwe University Ideato and environs using water quality index to determine its suitability for drinking and domestic purposes. Five borehole water samples were collected in the study area to evaluate the groundwater chemistry. The samples were sent to the laboratory within 24 hours for analysis. Electrical conductivity, turbidity and pH were calculated using their respective meters. The samples were examined for key cations (Ca, Mg, Na, Fe, and K), anions (HCO3, Cl, F, SO2, and NO3), total hardness, and dissolved silica (SiO2). In general, the results of the physicochemical analysis, except for iron, were below the allowable limits set by the Nigerian Industrial Standard and World Health Organization for drinking water. The water quality index (WQI) was calculated for the five water samples. This was then used to generate the groundwater quality map for the study area. The map shows that the highest WQI value of 41.42 is found at Senate Building KOMU while the lowest value of 29.74 is found at Amaikpa Ogboko. All the water samples are found to be excellent and potable for drinking.*

Keywords— *Concentration, geology, groundwater, physicochemical analysis, water quality.*

I. INTRODUCTION

Water is a vital component of our planet, and its importance cannot be overstated. Water unique properties make it essential for living organisms, ecosystems, climate and human consumption. Water has unique chemical properties due to its polarity and hydrogen bonds which means it is able to dissolve, absorb, or suspend many different compounds [1]. Thus, in nature, water is not pure as it acquires contaminants from its surrounding and those arising from humans and animals as well as other biological activities [2]. The primary sources of water are surface water such as fresh water lakes, rivers, streams, etc. and groundwater such as borehole water and well water. Over the year however, water, especially in the form of rivers, stream and ocean has traditionally served as a mean of waste disposal of materials such as faeces and other domestic waste products all over the world. Earlier groundwater was considered safe as compared to surface water but nowadays due to improper waste management pollution load increases in groundwater also [3]. The chemistry of subsurface water is controlled by many natural as well as anthropogenic factors. Natural factors which have control over water chemistry include precipitation pattern and amount, geological features of watershed and aquifer, meteorological factors, and various rock–water interaction processes in the aquifer [4, 5, 6]. Human activities which influence the water chemistry include dumping of solid waste, domestic and industrial waste, and mining and agricultural activities [7, 8, 9, 10].

Groundwater quality acts a crucial role in groundwater security and excellence preservation. Hence, evaluation of the groundwater quality is essential not only for use by present generation but also for future consumption [11, 12]. In the current study, an effort has been made to calculate the groundwater quality index of the study area for the aptness of groundwater resource for drinking and identify the influences of natural and anthropogenic actions on groundwater chemistry.

II. THE STUDY AREA

The study area is Kingsley Ozumba Mbadiwe University Ideato and environs, defined by latitude 05°49.14'N to 05°50.64'N and longitude 07°4.02'E to 07°5.76'E. It is situated in the rainforest belt of Nigeria, with lush vegetation and dense forests. The area is predominantly a rural area used for farming, with crops like yams, cassava, maize, and palm trees being commonly cultivated. Some major communities within the study area include: Ogboko, Umuchima, Urualla, Obiohia and Ogume. The study area borders the Okigwe and Oru East LGAs to the east, Orlu LGA to the west, and Nkwerre and Nwangele LGAs to the south.

Figure 1: Map showing the study area

The area is quite accessible with a network of tarred and untarred roads. There are topographic high and low areas observed across the study area. The area is not well drained. The Orashi river flows along the boundary between Orlu LGA

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and the study area. On the Eastern part there are few tributaries of the rivers that drain the adjacent Local Government areas of Okigwe and Omuma which flow into the Imo River [13].

III. Geology of the Study Area

The regional geology of the study area is that of the Imo River basin (Figure 2). It is located in the southeastern Nigeria. The Imo River basin is situated within the Niger Delta basin, a sedimentary basin that covers much of southern Nigeria. The basin is characterized by six major stratigraphic units: The Benin Formation, the Ogwashi- Asaba Formation, the Bende-Ameki Formation, the Imo Shale group, Nsukua Formation and Ajali Sandstone Formation. The geological formation of the study area is Ameki Formation and it overlies the Imo Shale group. The Benin Formation contains some isolated gravels conglomerates and very coarse sandstone in some places. Thickness of the Benin Formation is about 800m at its depocenter while the mean depth to water table is about 24m [14]. The Benin Formation is overlain by alluvium deposits and underlain by Ogwashi-Asaba Formation which consists of lignite, sandstones, clays and shales. The Benin Formation provides the condition for Groundwater storage because of its high porosity and permeability. The Ogwashi- Asaba Formation is made up of variable succession of clays, sands and grits with seems of lignite while the Ameki Formation consists of greenish – grey clayey sandstones, shales and mudstones with interbedded limestones. This Formation in turn overlies the impervious Imo Shale group characterized by lateral and vertical variations in lithology. It is underlain in succession by Nsukka Formation, Ajali Sandstones and Nkporo Shales [15] Sediments of Imo Shale Formation consist of well laminated plain Shale with grey to light green colour. The shale contains occasional intercalations of thin bands of calcareous Sand Sandstones, marls and limestone. The Imo Shale Formation is of Paleocene age. Groundwater exploration is very difficult in this Formation [16].

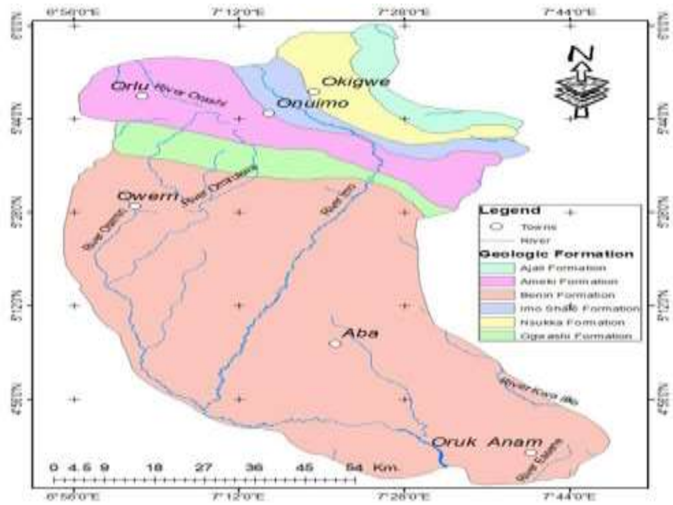

Figure 2: Geology map of Imo River basin [17]

IV. Methodology

Five groundwater samples were collected in the study area to evaluate the groundwater chemistry. The samples were collected in 1.5 liters Polyethylene containers cleansed with sampled water before filling and then immediately corked after to avoid the oxidation of the constituents with oxygen. The samples were adequately labeled. Groundwater samples were collected after flushing water 5–10 min in order to eliminate the intervention of the stagnant water in the metal shell and to even out the electrical conductivity [18]. The samples were sent to the laboratory within 24 hours for analysis.

Electrical conductivity (EC), turbidity and pH were calculated using pH, turbidity and conductivity meters after calibration of the meter with standard buffers of respective parameter. The samples were then examined for key cations (Ca, Mg, Na, Fe, and K), anions (HCO_3, Cl, F, SO_2, and NO_3), total hardness, and dissolved silica (SiO_2). The total dissolved solids was determined directly by analysis of the filtered sample for total solids (gravimetric method). The chemical analysis of the water samples was carried out according to the procedure given in [19]. The results obtained were practice for comprehensive geochemical investigation.

V. Water Quality Evaluation

The water quality index (WQI) is used for water excellence evaluation. WQI is a numerical value that represents the overall quality of water based on various parameters. It is based on physical, chemical, and biological factors that are combined into a single value that ranges from 0 to 100, or above and involves four processes which are: (1) parameter selection for measurement of water quality, (2) transformation of the raw data parameter into a common scale, (3) providing weights to the parameters and (4) aggregation of sub-index values to obtain the final WQI.

The WQI has been calculated to evaluate the suitability of groundwater quality of the study area for drinking purposes. Nine parameters (pH, TDS, Na, K, Mg, Ca, Cl, Fe, HCO_3) were taken into account and the standards for human consumption as suggested by [20] have been taken for the estimation of WQI in this study. Firstly, special weights (w_i) in a scale of 1 (slightest consequence on water quality) to 5 (highest outcome on water quality) was allocated to every elemental parameter, on the basis of their supposed impact on primary health and their relative magnitude in the quality of drinking water [21]. The parameters having serious health impact and whose occurrence above the critical concentration amount could result in confined usage of the resource for household and drinking purposes were given the highest weight five [22]. The highest weight of 5 has been allocated to chloride, because of its foremost significance in water excellence evaluation [23]. The least weight of 1 is given to bicarbonate, as it is less prominence in the water quality evaluation. Other parameters like calcium, magnesium, iron, TDS, sodium, potassium and pH were allocated specific weight between 2 and 4 depending on their prominence in water quality evaluation. Weight and relative weight of the physicochemical parameters is given below in Table 1.

The relative weight of each parameter of the water sample is determined using the equation:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} wi} \qquad (1)$$

Where, W_i = Relative weight

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w_i = Allocated weight of each parameter
n = Number of parameters.

TABLE 1: Chemical parameters and their relative weight

Chemical parameters	WHO standards (2011) (mg/l)	Weight (w_i)	Relative weight (W_i)
TDS	500*	4	0.13
Bicarbonate	200 - 500	1	0.03
Chloride	250 - 500	5	0.17
Calcium	75 - 200	3	0.10
Magnesium	50 - 100	3	0.10
Sodium	200 - 600	4	0.13
Potassium	10 - 12	2	0.07
pH	6.5 - 8.5	4	0.13
Fe	0.3*	4	0.13

*Nigerian Industrial Standard (2007) values

The quality rating (q_i) is thus calculated for each parameter by dividing its concentration in the water sample by its permissible limits values given by the WHO and multiply by 100:

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

Where, q_i = Quality rating for ith parameter
C_i = Concentration of ith parameter of water sample (mg/L)
S_i = WHO standard for ith chemical parameter of water sample (mg/L).

Finally, to compute WQI, we first calculate the SI_i of each parameter using Equation (3) and summing up the values of all the parameters of the water sample.

$$SI_i = W_i \times q_i \quad (3)$$

$$WQI = \sum SI_i \quad (4)$$

SI_i is the sub-index of the ith parameter; q_i is the quality ranking which depends on the amount of *i*th parameter. WQI standards are divided into five categories: Excellent (<50), Good (50–100), Poor (100–200), very poor (200–300), and Unsuitable for drinking (>300) [24, 9].

TABLE 2: Ranges of WQI types of water [20]

Range	Type of water
<50	Excellent water for drinking
50 - 100	Good water for drinking
100.1 - 200	Poor water for drinking
200.1 - 300	Very poor water for drinking
>300.1	Water unsuitable for drinking purpose

VI. RESULTS AND DISCUSSION

The data of physicochemical analysis of the groundwater samples is given in Table 3. The quality and suitability of the water resources for drinking and domestic purposes were determined by comparing laboratory results with [25] maximum permissible limits and discussed wit*h t*he national and international water quality standards set for drinking water. In general, the results of the physicochemical analysis, except for iron, were below the allowable limits set by [25, 20].

TABLE 3: Physicochemical data of groundwater samples in t*he study area (Values in mg/L except p*H, EC and turbidity)

Parameters	NIS (2017)	Obiohia			Amaikpa Ogboko			Benahillz Hotel Ogboko			Umuokwaraocha Umuchima			Senate Building		
		Run 1	Run 2	Mean	Run 1	Run 2	Mean	Run 1	Run 2	Mean	Run 1	Run 2	Mean	Run 1	Run 2	Mean
pH	6.5-8.5	6.26	6.26	6.26	5.99	5.99	5.99	5.86	5.86	5.86	5.64	5.64	5.64	6.06	6.06	6.06
TDS	500	13.00	13.00	13.00	20.15	20.15	20.15	16.90	16.90	16.90	17.55	17.55	17.55	16.90	16.90	16.90
Conductivity	1000	20.00	20.00	20.00	31.00	31.00	31.00	26.00	26.00	26.00	27.00	27.00	27.00	26.00	26.00	26.00
Turbidity	5.00	2.00	1.90	2.00	0.50	0.40	0.45	0.80	0.70	0.75	1.50	1.40	1.45	2.30	2.20	2.25
Calcium Hardness	100.00	5.18	5.18	5.18	7.77	10.36	9.07	10.36	10.36	10.36	10.36	10.36	10.36	12.95	7.77	10.36
Total Hardness	100.00	10.36	10.36	10.36	18.13	23.31	20.72	20.72	15.54	18.13	18.13	15.54	16.84	51.80	51.80	51.80
Magnesium Hardness	100.00	5.18	5.18	5.18	10.36	12.95	11.66	10.35	5.18	7.77	7.77	5.18	6.48	38.85	44.03	41.44
Total Chloride	100.00	23.99	21.99	22.99	22.99	22.99	22.99	25.99	24.99	25.49	24.99	23.99	24.49	22.99	20.99	21.99
Nitrate	10.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sulphate	100.00	ND	ND	ND	1.32	1.58	1.45	0.79	0.79	0.79	1.05	1.05	1.05	8.95	8.95	8.95
Calcium	200.00	1.49	1.49	1.49	2.23	2.98	2.61	2.98	2.98	2.98	2.98	2.98	2.98	3.72	2.23	2.98
Magnesium	2.00	1.26	1.26	1.26	2.52	3.15	2.84	2.52	1.26	1.89	1.89	1.26	1.58	9.45	10.71	10.08
Bicarbonate	NS	0.99	0.99	0.99	1.99	0.99	1.49	1.99	0.99	1.49	1.99	1.99	1.99	7.99	7.99	7.99
Iron	0.30	0.43	0.45	0.44	0.36	0.35	0.36	0.37	0.37	0.37	0.36	0.36	0.36	0.47	0.47	0.47
Sodium	100.00	0.15	0.14	0.15	0.10	0.10	0.10	0.03	0.02	0.03	0.20	0.19	0.20	0.24	0.24	0.24
Potassium	10.00	5.50	5.33	5.42	3.50	3.17	3.34	2.50	2.67	2.59	5.83	5.50	5.67	13.33	13.00	13.17
Fluoride	NS	ND	ND	ND	110.0	111.11	110.55	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silicate	NS	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Note:
ND - None Detected
NS - Not Stated

pH

The pH of the water samples ranges from 5.64 to 6.26. This shows a pH less than 7 thus indicating that the water is slightly acidic. This also falls below [25] standard for drinking water which is 6.5 - 8.5. The slight acidity could be from the already polluted orashi river or an open waste dumpsites within the study area, making the leacheate find it way easily to infiltrate into the aquifer system. But basically, the geology of the soil (lateritic sand) may be the reason for the slight acidic water in the study area.

Total Dissolved Solids (TDS)

Using classifications on the basis of TDS by [26], the value range of 13 to 20.15mg/L identified all the water samples in the study area as excellent for drinking. Classification of water on the basis of TDS after [27] also shows that the water in the study area is freshwater.

TABLE 4: Total Dissolved Solids (TDS) after [27]

TDS (mg/L)	Descriptions
0 - 1000	Fresh water
1000 - 10000	Brackish water
10000 - 100000	Saline water
> 100000	Brine water

Conductivity

Electrical conductivity (EC) values vary from 20 to 31µS/cm in the study area. Based on [28] classification of water using EC values, all the water samples from the study area fell into the "excellent water" category which signifies water of low salinity.

TABLE 5: Classification of water according to EC values [28]

Range of EC (µS/cm)	Category
0 -333	Excellent
333 - 500	Good
500 - 1100	Permissible
1100 - 1150	Brackish
1500 - 10,000	Saline

Turbidity

Turbidity was measured in nephelometric turbidity units (NTU) and ranges from 0.45 to 2.25 NTU in the study area. These values are within acceptable [25] maximum limit of 5 NTU, which indicate the waters in the study area are clear. Turbidity is the amount of clarity or cloudiness in the water. This can vary from a river full of mud and silt where it would be impossible to see through the water (high turbidity), to a spring water which appears to be completely clear (low turbidity). Turbidity can be caused by silt, sand, and mud, bacteria and other germs, and chemical turbidity. Turbidity water can be a sign of waterborne pathogens.

Total Hardness

The total hardness values range from 10.36 to 51.8mg/L in the study area. According to the total hardness values in the Table 6, the water samples from Obiohia, Amaikpa Ogboko, Benahillz Hotel Ogboko and Umuokwaraocha Umuchima are soft. The low total hardness values may be due to the low concentrations of dissolved divalent metallic ions, calcium and magnesium [20]. The water sample from Senate Building KOMU is moderately hard. All the groundwater samples in the study area are less than the hardness of water that may cause heart diseases and kidney problems.

TABLE 6: Classification of water according to its hardness

Water classification	Total hardness concentration as mg/L as as $CaCO_3$
Soft water	<50mg/L as $CaCO_3$
Moderately hard	50 - 150 mg/L as $CaCO_3$
Hard water	150 - 300mg/L as $CaCO_3$
Very hard	>300 mg/L as $CaCO_3$

Total Chloride

The values of chloride range from 21.99 to 25.49mg/L which fall within [20] standard for drinking water. Chloride is not typically considered harmful to human at low concentration but could affect the taste and quality of water. Very low levels may be associated with reduced stomach acid production, potentially leading to digestive issues in some individuals. Higher chloride content value above 500mg/L [20] is an indicator of polluted water chloride

Nitrate

Nitrate is an essential ingredient of plant nutrition. It is however regarded as an indicator of pollution in public water supply [29]. The [30] standard for nitrate in drinking water is 10mg/L. No nitrate content however was detected in all the samples. The absence of nitrate concentration in the water could be as a result of the presence of soils with high organic matter content or the geological settings of the study area such as low groundwater recharge, groundwater flow which removes or dilutes the nitrate from groundwater as it flows through the aquifer and deeper depth to water table. The absence of nitrate in drinking water is not typically considered harmful to health. In fact, high levels of nitrate in drinking water can be harmful, particularly for infants and pregnant women.

Sulphate

The sulphate content in the water samples ranges from 0.79 to 8.95mg/L, except in Obiohia where it was not detected, and considered generally low compared with safe limit of 100mg/L prescribed by [25]. The absence of sulphate content in drinking water could make it taste flat or bitter and low sulphate levels may lead to digestive issues. There is no health impact recorded for high sulphate intake [31]. Excess concentrations of sulphate in groundwater not an indication to health hazard but can cause scale formation and may lead to a bitter taste in water which can result in laxative effect of humans and young livestock [32].

Calcium and Magnesium

T*he maximum values for Ca and Mg in t*he water samples were 2.98 and 10.08mg/L respectively and the minimum values were 1.49 and 1.26mg/L. On average, the contents of calcium and magnesium in drinking water of all the samples do not meet the 20 - 30mg/L and 10mg/L respectively as suggested by epidemiological research for health benefits. The low concentrations of Ca and Mg ions in the waters could be due to the limited occurrence of calcic and ferromagnesian mineral-bearing rocks. Low concentrations of Ca and Mg in drinking water could cause increased risk of cardiovascular disease, weakened bones and teeth (osteoporosis) and muscle cramps and spasms. High concentrations could however cause gastrointestinal issues (constipation, bloating), kidney stone formation (due to excess calcium) and cardiovascular problems (due to excess magnesium).

Bicarbonate

The concentrations of bicarbonate HCO_3 range from 0.99 to 7.99mg/L in the study area and are below the 200 - 500mg/L permissible limit set by [20]. This low concentration of HCO_3 could be caused by groundwater interacting with rocks and soil

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low in bicarbonate minerals, groundwater flowing through acidic soil and rocks or excessive rainfall and runoff which can dilute bicarbonate levels in groundwater. Water with low bicarbonate levels may taste sour or unpleasantly sharp, contribute to tooth decay, exacerbate heartburn, acid reflex, and kidney indigestion and increase the risk of developing kidney stones. Excess of it in drinking water makes the water taste soapy, bitter, or unpleasantly sweet and may cause stomach upset, nausea, vomiting, and diarrhea.

Iron

The iron content in the samples ranges from 0.36 to 0.47mg/L, higher than [30, 25] maximum permissible of 0.3mg/L. One crucial factor to account for the high iron content is the lateritic soil found in the study area. This type of soil or sediment is rich in iron (often reddish or yellowish in colour) and aluminum oxides with low silica content, high porosity and permeability and is often found in areas with high rainfall and good drainage. As rainwater passes through the ground and rock, it dissolves some of the iron, carrying it into groundwater source. Iron is one of important element useful in the body system. Moreover, iron toxicity could lead to water having a metallic or rusty taste and smell, skin irritation, rashes and hair decoloration, liver malfunctioning and diabetes mellistus.

Sodium

The sodium concentrations of groundwater in the study area vary between 0.03 to 0.24mg/L, which fall below the permissible limit of 100mg/L set by [25]. The reason for this low sodium content could be caused by human activities in the study area such as over-extraction of groundwater and poor well construction, or by inadequate aquifer recharge that can lead to reduced sodium levels. Sodium content in drinking water can improve taste and palatability of water and maintain fluid balance and blood pressure. Excessive sodium consumption can however lead to various health issues.

Potassium

The potassium content of 13.17mg/L in the water sample from Senate Building KOMU is far greater than the rest samples. This value is higher than [25, 20] standards of 10 - 12mg/L for drinking water. Others fall below the permissible limits. The high potassium content could be from nearby soil contamination with high potassium level leaching into the groundwater, overuse of potassium-based fertilizers or manure or improper disposal of potassium-containing waste, like electronics or batteries around the location. Adverse health effects due to high potassium consumption from drinking water are unlikely to occur in healthy individuals. Potassium intoxication by ingestion is rare because potassium is rapidly excreted in the absence of pre-existing kidney damage and because large single doses usually induce vomiting [33]. High-risk individuals (individuals with kidney dysfunction or other diseases such as heart disease, coronary artery disease, hypertension, diabetes, adrenal insufficiency, pre-existing hyperkalaemia; people taking medications that interfere with normal potassium-dependent functions in the body; and older individuals or infants) are recommended to avoid elevated potassium intake from drinking water.

Fluoride

The fluoride concentration in four water samples was not detected. Only the sample from Amaikpa Ogboko has a fluoride content of 110.56mg/L. The absence of fluoride in those samples in the study area could be due to the geology of the soil or groundwater flowing through older rocks and sediments that causes natural depletion of fluoride over time. A moderate amount of fluoride concentration in drinking water contributes to good dental health. About 1.0mg/L is effective in preventing tooth decay, particularly in children [19, 34]. Excessive amounts can however cause discolored teeth, a condition known as dental fluorosis.

Dissolved Silicate

All the water samples in the study area do not potentially contain any silicate content in them. This could be as a result of the aquifer material having a low silica content or the groundwater pH is low (acidic), as observed in the study area (geology of *the soil)*. Silicates are more soluble in alkaline environments. The absence of silicate in drinking water may result to the water tasting bitter or unpleasant and may cause dental health issues. [35] recommends 17mg/L permissible limit for silicate in drinking water

VII. WATER QUALITY INDEX

The WQI was calculated for the five available groundwater samples in the study area using the chemical parameters in Table 1. This was then used to generate the groundwater quality map for the study area (Figure 3).

TABLE 7: Results of water quality index of the study area

Location	Longitude E(Degree)	Latitude N(Degree)	WQI	Type of water
Senate Building KOMU	7.08083	5.82563	41.42	Excellent
Amaikpa Ogboko	7.08517	5.74070	29.74	Excellent
Benaillz *h*otel Ogboko	7.08852	5.82615	30.36	Excellent
Umuduruanyanwu Obio*hia*	7.07695	5.83897	34.18	Excellent
Umuokwaraoc*ha* Umu*ch*ima	7.07307	5.82892	30.43	Excellent

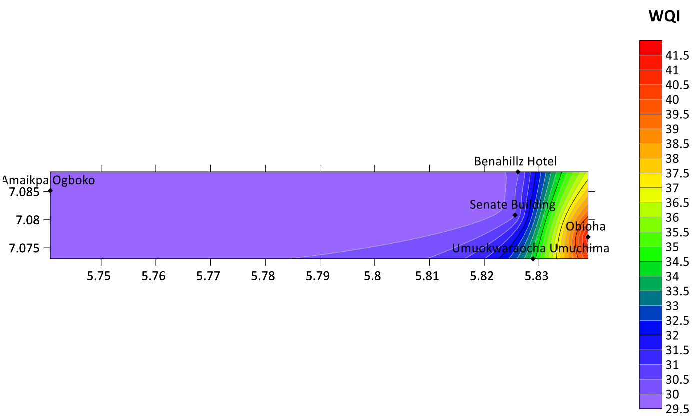

Figure 3: Groundwater quality map of the study area

The map shows that the highest WQI value of 41.42 is found at Senate Building KOMU while the lowest value of 29.74 is found at Amaikpa Ogboko. According to [20] (Table 3), all the groundwater samples are excellent and potable for drinking.

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The high value of WQI at Senate Building KOMU has been observed due to elevated concentrations of total hardness, potassium and bicarbonate in the groundwater sample. This change of pattern may be due to effective leaching of ions on large extent impact.

VIII. CONCLUSION

From the groundwater quality analysis, it can be concluded that the geochemistry of the study area is controlled by both natural and anthropogenic factors. The groundwater samples have pH values between 5.0 - 6.5 which does not meet the permissible limits for drinking water. This is typical of a water type coming from a slightly acidic to acidic soil with high iron and aluminium content, low silica and high organic matter content such as lateritic soils. This soil type is formed in tropical and subtropical regions, particularly in areas with high rainfall and good drainage. The iron content in all the water samples falls above the national and international standards for drinking water. Silicate and Nitrate were not detected in any of the samples, while sulphate content was only detected in one sample. One crucial factor for these anomalies is also due to the geology of the soil in the study area. The highest value of WQI was obtained at Senate Building KOMU. This may have resulted from the increased pollution arising from increased domestic activity, agricultural practices and wastewater disposal with the leachates finding it way into the aquifer system.

The outcomes obtained from the study will be helpful to identify high-risk areas, prioritize protection and management efforts, develop targeted strategies for pollution prevention and remediation and ensure sustainable groundwater resource management.

Disclosure statement

No potential conflict of interest was reported by the authors

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