International Journal of Academic Engineering Research (IJAER)
ISSN: 2643-9085
Vol. 8 Issue 8 August - 2024, Pages: 39-48

Groundwater Quality Index for Ozuoba, Obio/Akpor Local Government Area, Rivers State, Nigeria

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Abstract: *The Canadian Water Quality Index (CWQI) was used in this study to evaluate the quality of an area of groundwater from boreholes in Ozuoba, Obio/Akpor Local Government Area, Rivers State, Nigeria. The study found that the eleven parameters that comprised the CWQI were as follows: pH, turbidity, calcium, magnesium, chloride, conductivity, dissolved oxygen, sulphate, total hardness, total alkalinity, and total dissolve solid. In the Ozuoba Obio/Akpor Local Government Area, three boreholes were chosen at random and subjected to standard and analytical techniques for testing. Ogbogoro scored 84.2%, which is good, Ozuoba scored 100%, which is exceptional, and Rumuokwachi scored 90.6%, which is good, according to the CWQI results. Based on the results, they show that the chosen borehole water samples' water quality complies with WHO drinking water standards.*

Keywords - Groundwater Quality, Canadian Water Quality Index, Physicochemical Parameters, Bacteriological Parameters

1. INTRODUCTION

The water found in the pore spaces of rocks, soil, and rock formation fissures beneath the surface of the Earth is generally referred to as groundwater. Because groundwater is not likely to dry out naturally, it offers a reasonably consistent supply for irrigation, home use, and cattle, reducing the effects of rainfall. In many and semi arid regions of Africa borehole water is a technique of coping with water limitations in locations where rainfall is rare or highly seasonal and surface water is extremely limited [1]. Pollution of Water Regretfully, pure, safe, and uncontaminated water are fleeting in nature, since they are quickly contaminated by human activity and prevailing environmental variables. Even precipitation falls from the sky can carry pollutants including sulfur dioxide, carbon dioxide, and particle matter from road erosion. Flare gas with sulfuric acid produce what is known as "acid rain" conditions [2].
Because of the proximity of the water table to the soil's surface, the porous layers that tap the table, and the abundance of superficial sources of contamination, ground water looks to be just as vulnerable as surface water [3].
World population cannot be sustained without access to safe water [4]. Therefore, when managing water resources, it's critical to take both water quality and quantity into account simultaneously [5]. Borehole water becomes unsuitable for domestic use as a resource due to contamination that makes it unfit [6]. The objective of water quality management is usually to limit the health risks associated with either direct or indirect use of water [7]. The world health organization (WHO) suggests that the minimum amount of water consumed daily per capita should be 27 liters per person per day. As the population grows, the need for food and other services will also rise, which will raise the demand for water [8]. Due to this, there are now more issues associated with using ground water resources, including ensuring sufficient quantity and quality [9].

When it comes to the usage of groundwater by humans, the most obvious issue is that the water table is falling below the level of current wells. In order to access groundwater, wells must be dug deeper; as a result, widespread well pumping has caused the water table to drop hundreds of feet in some locations (such as California, Texas, and India) [10].
Land subsidence, or a dip in the ground surface, can result from the aquifer becoming crushed [11]. In unconsolidated aquifers, groundwater is produced from pore spaces between particles of gravel, sand, and silt. If the aquifer is confined by low-permeability layers, the reduced water pressure in the sand and gravel causes slow drainage of water from the adjoining confining layers. But more intense drought periods could result in soil drying-out and compaction which would reduce infiltration to groundwater [12]. A pH that is close to neutral (pH7), according to [13] is a sign of pure water whole dissolved material. The concentration of all dissolved minerals in water is known as total dissolve solid, or TDS. A wide range of both ionic and due to the weathering of minerals from acids created as byproducts of the deterioration process can be found in natural waters. As a result, TDS is a geochemical characteristic that directly connects microbial hydrocarbon degradation to bulk conductivity [14]. Another source of ground water nitrate is leftover urea that seeps into the ground and is broken down by microorganisms [15].
The total and fecal forms of coliform bacteria are indicators of the presence or lack of harmful microorganisms, and [16] state that this determines the hygienic quality of water.
In various investigations, [17] found that almost all of the aqueous pollutants from the businesses in Ozuoba and the surrounding area are discharged into streams. Additionally, some spills occur on the land and seep into the earth, endangering the water quality.

Water contamination can be prevented by placing boreholes far from any sources of pollution [18]. Based on the Bayesian expert for flow field modeling, the kind and loads of contaminants transferred from the land fill site to the nearby aquifer, as well as the size of leachate plumes within the groundwater, were evaluated for site inquiry and borehole positioning [19].

Before water is acceptable for human consumption, it must meet certain physical, chemical, and bacteriological quality standards [20]. Thus, according to [2], water quality can be determined by a variety of factors that restrict water consumption. More stringent maximum contaminants are not the familiar traditional enemies in the water treatment circle, as a result of numerous emerging water issues that have forced many developing nations, including the United States of America, France, and Great Britain, to continuously revise their water quality standards and treatment criteria over the last 20 years.

By combining measurements of ten carefully chosen water quality indices (DO, BOD, TDS, pH, turbidity, temperature, nitrate, sulfate, chloride, and iron), the Water Quality Index (WQI) is a single figure that indicates water quality. It creates a score that characterizes overall water quality by harmonizing a predetermined set of water quality criteria.

According to [21], a water quality index offers a practical way to condense complicated water quality and make it understandable to a broad audience. The communication of data to management and the general public, in his opinion, is an essential component of any program involving environmental monitoring.

By using an index that will mathematically aggregate all water quality parameters and produce a general, easily understood description of water, the water quality index lessens the multivariate character of water quality data. Even so, numerous attempts have been made to raise the water quality index. The British Canadian Ministry of Environment's (CCME) index seems to be the most successful attempt to date.

A committee of the Canadian Council of Ministers of Environment developed the Canadian Ministers of the Environment (CCME) water quality index in 1997. It was based on the British Columbia (BC) index. It includes the adjustments made by the Albertan province, and it bears a strong resemblance to the Alberta Agricultural Water Quality Index [22]. The water quality index is maintained by the Canadian Ministers of Environment (CCME). According to [23], the index is based on three components, each of which has been scaled to fall between 0 and 100. Water quality measurements indicate the degree of contamination present in water resources and indicate if the water is fit for human use. Due to the negative health effects and low consumer aesthetic value, contaminated water is unacceptable [24]. The standardized scores for each water quality parameter are based on predetermined rating curves, such that a score of 100 indicates excellent water quality and a score of 0 indicates poor water quality. According to [25] developed an index of river water quality in Taiwan that is a multiplicative aggregate function of standardized scores for temperature, pH, toxic substances, organics (dissolved oxygen, BOD, ammonia), particulate (suspended solids, turbidity), and microorganisms (faecal coliforms). The index is based on the geometric means of the standardized scores.

According to [26], created a chemical water quality index by adding together the concentrations of seven water quality parameters (total nitrogen, dissolved lead, dissolved oxygen, pH, and total, particulate, and dissolved phosphorus) after standardizing each observation to the maximum concentration for each parameter. The data came from 18 streams in a single lake basin in northern Alabama.

The three well water samples were analyzed using the Canadian Water Quality Index, which revealed the following overall quality ratings: W1: 35.85% (poor), W2: 36.32% (poor), and W3: 37.42% (poor). The water was deemed poor primarily because of elevated chemical and bacteriological parameter values that contributed to an increase in composition effect on drinking water quality [27].

The Overall Index of Pollution (OIP) for Indian rivers based on measurements and subsequent classification of pH, turbidity, dissolved oxygen, BOD, hardness, total dissolved solids, total coliforms, arsenic, and fluoride was developed [28]. The Canadian Water Quality Index (CWQI) compares observations to a benchmark, where the benchmark may be a water quality standard or site specific background concentration [23].

2. MATERIALS AND METHODS

Study Area

The study was carried out in Ozuoba in the Obio/Akpo Local Government Area in Rivers State, Nigeria, which is west of Port Harcourt. The area is also an agricultural zone with a variety of farming practices and agricultural activities being practiced, and the use of different pesticides and fertilizers is also encouraged to boost the agricultural produce for the growing population as well as mitigation on unpredictable climate changes.

The three communities that make up the research region are Ogbogoro, Ozuoba, and Rumuokwachiz, as indicated by the map in Fig. 1. The water from some of these villages' bore holes is contaminated by septic tanks, improper farming methods, cemeteries next to bore holes, and trash disposal.

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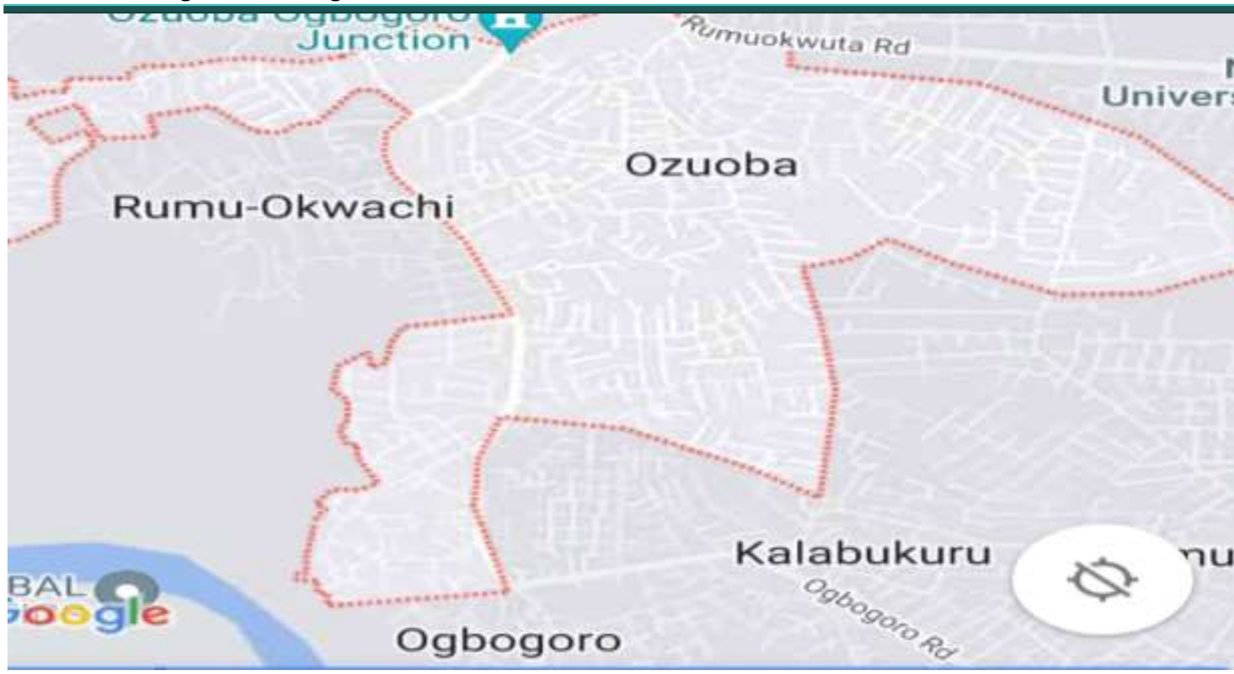

Fig. 1. *Location of Ozuoba Obio/Akpor Local Government Area*

Sample Analysis

On-site analysis was conducted using the Hanna combo H198129 waterproof tester for non-conservable parameters (pH and total dissolved solids, or TDS) that were significant in determining the study's water quality index. The nephelometric method was also used to determine the turbidity on-site.

Laboratory Analysis

Eleven parameters, including nitrates, phosphate, calcium, magnesium, chlorides, sulphates, fluorides, iron, total phosphorous, total hardness, total alkalinity, and total coliforms, were measured on the samples at Rivers State University laboratory. These parameters were characterized using the World Health Organization (WHO) standards and the standard methods for physiochemical and bacteriological parameters provided by APHA. For example, the spectrophotometric approach was used to determine total hardness, phosphate, nitrate, iron, and fluorides. In order to determine fluoride, the absorbance is set at 570 nm. The titration method was used to determine the amounts of magnesium, calcium, chloride, and sulphate.

Collection and Preparation of Samples

A two-minute flush was performed on each borehole to eliminate any contamination caused by external sources. The 250 ml bottles were sterilized by adding 0.1 ml of sodium thiosulphate. After that, the boreholes were pumped full of water bottles, leaving a 2.5 cm gap in between to allow for oxygenation and prevent organisms from dying before laboratory testing. The labels for every borehole in the neighborhood and each borehole were used to identify the bottles. After that, the bottles were brought to the lab in an insulated box, or cooler, to avoid having outside influences, like high temperatures, alter some of the water's properties. After sampling, analysis started within 12 hours.

Analytical Methods

The process advised in the standard techniques for the testing of water and wastewater [29] was followed by the adopted methods of analysis for the examination of all parameters in the well water samples. Selected physicochemical and microbiological characteristics were examined in all samples.

Method of Data Analysis

The Canadian water quality approach [30] was used to construct the Water Quality Index (WQI) for each sample. The parameters utilized for the water quality indices in this study were carefully chosen to correctly reflect the main acceptability and health concerns associated with water quality.
As indicated in Table 3, thirteen factors were chosen utilizing the CCME/WHO standard. Table 3: Parameters of Water Quality World Health Organization Standard. Standard Parameter Total suspended solids (mg/l) at pH 8.5 05 Total Solids Dissolved (mg/l) 500 Hardness overall (mg/l) 300 Conductivity of Electricity 300 Iron concentration (mg/l) 0.3 mg/l of lead (Pb) 0.01 mg/l of cadmium (Cd) 0.003 mg/l of chloride ions 250 milliliters of alkalinity 200 All of the heterotropic bacteria One coliform bacterium overall 10 Bacteria causing fecal coliform (mg/l) 10 [29–31] Index of Water Quality in Canada Three measurements of deviation from certain water quality targets make up the Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI) model: scope, frequency, and amplitude.
The total water quality is represented by a value between 0 and 100, which is the result of combining these three measures of variance (UNEP GEMS/Water Programme, 2007). [30]. Then, using the list order structure described in Table 4 below, the CCME WQI values are converted into rankings. Table 4: Water Quality Index Categorization Schema by the Canadian Council of Ministers of the Environment. WQI Value Description Ranking Outstanding 95–100 Conditions are extremely close to natural or pristine levels, protecting the water quality. These index values can only be attained if all measurements are almost always within the predetermined ranges.

Excellent 80-94 there is no threat or degradation to the protected water quality, and conditions hardly ever deviate from ideal or natural levels. Just 65-79 Water quality is typically safeguarded by periodically being threatened or compromised; circumstances can occasionally deviate from ideal or natural levels. Marginal 45–64 Water quality is regularly in jeopardy or compromised; circumstances frequently deviate from ideal or natural thresholds. Bad 0-44 almost often, there is a threat to or degradation of the quality of the water; conditions typically deviate from ideal or natural levels [30].

WQI Designations

A number between 1 and 100 is produced using the index equation, where 1 represents the lowest water quality and 100 the highest. Canadian Council of Ministers of the Environment established classifications to categorize water quality as low, marginal, fair, good, or exceptional within this range.
Calculation of the Canadian Water Quality Index The detailed formulation of the WQI, as described in the Canadian Water Quality Index 1.0 – Technical Report [30], is as follows:

$$\mathrm{F_1} = \left(\frac{\text{Number of failed variables}}{\text{Total number of variable}}\right) \times 100 \qquad (1)$$

F2 for frequency F2 is the frequency measure. This is the percentage of individual tests (also known as "failed tests") that do not meet the objectives.

$$F_2 = \left(\frac{\text{Number of failed test}}{\text{Total number of tests}}\right) \times 100$$

The quantity, F3 F3 is the amplitude measurement. This is the percentage that failed tests fall short of their goals. This can be computed in three steps:
Step 1: Excursion Calculation The number of times an individual concentration exceeds (or falls short of, if the target is a minimum) the objective is known as the excursion. When the test value can't go over the goal:

$$\mathrm{Excursion_i} = \left(\frac{\text{failed test value i}}{\text{Objectives j}}\right) - 1 \times 100 \qquad (2)$$

In situations when the test value cannot be lower than the goal:

$$\text{Excursion}_{\text{i}} = \left(\frac{\text{Objectives j}}{\text{failed test value i}}\right) - 1 \times 100 \qquad (3)$$

Step 2: Normalized Sum of Excursions Calculation The total amount that each test is out of conformity with the others is known as the normalized sum of excursions, or nse. This is computed by taking the total number of tests (both those that meet and do not meet objectives) and dividing it by the sum of the excursions of each test from its objectives.

$$\text{NSE} = \frac{\sum_{1=i}^{n} \text{excursion } i}{\text{Total number of tests}} \qquad (4)$$

Step 3: F3 is computed using an asymptotic function that produces a range from 0 to 100 by scaling the normalized sum of the deviations from the objectives.

$$F_3 = \left(\frac{\text{NSE}}{0.01\text{NSE} + 0.01}\right) \qquad (5)$$

The CWQI is then calculated as:

$$\text{CWQI} = 100 - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732}\right) \qquad (6)$$

The classification scheme presented in Table 1 is then used to convert the CWQI values into rankings. Through this interaction, the crude WQ information in the CCME WQI is transformed into data (the quantity and frequency of boundaries that exceeded the rules) and then into information (the water's suitability for drinking, such as Great, Great, Fair, or Poor). The description of each sampled station is shown in Table 2.

Table 1: Canadian Water Quality Index (CWQI) Designations

Designation	Index value	Description
Excellent	95-100	All measurements are within objectives virtually all of the time
Good	80-94	Conditions rarely depart from natural or desirable levels
Fair	65-79	Conditions sometimes depart from natural or desirable levels
Marginal	45-64	Conditions often depart from natural or desirable levels
Poor	0-44	Conditions usually depart from natural or desirable levels

Table 2: Description of Each Sampled Station

S/N	STATIONS	DESSCRIPTIONS
1	WQA-OG	Ogbogoro
2	WQA-OZ	Ozouba
3	WQA-RK	Rumuokwachi

3. RESULTS AND DISCUSSION

Results

The results of the physicochemical and microbiological analysis quality of Ogbogoro, Ozuoba and Rumuokwachi ground water are presented in Table 3. The Calculations of Canadian Water Quality Index (CWQI) and the Canadian Water Quality Index (CWQI) of the Groundwater of three communities with classification are shown in Tables 4 and 5.

Table 3: Values of the Test Conducted From the Samples

Parameter	**Unit**	**Station 1**	**Station 2**	**Station 3**	**Standard**	**Reference agency**
pH	pH scale	6.55	6.76	6.51	8.5	WHO
Turbidity	N-T-U	3.81	2.12	3.30	5	WHO
Calcium	mg/l	80.48	40.16	50.15	75	WHO
Magnesium	mg/l	9.18	8.31	8.13	20	WHO
Chloride	mg/l	74.70	68.30	97.60	250	WHO
Conductivity	µs	82.20	97.80	92.20	100	WHO
Dissolved oxygen	mg/l	7.0	6.18	8.0	7	WHO
Sulphate	mg/l	39.50	53.90	82.27	400	WHO
Total hardness	$mgCaCO_3/l$	79.80	48.70	90.60	500	WHO
Total alkalinity	$mgCaCO_3/l$	96.12	82.57	88.40	400	WHO
TDS	mg/l	69.0	73.94	141.60	500	WHO

Table 4: The Calculations of Canadian Water Quality Index (CWQI)

Sample No	1	2	3
No of failed variable	2	0	1
F1	18.2	0	9.1
No of failed test	2	0	1
F2	18.2	0	9.1
The normalized sum of excursions (N)	1.1	0	0.1
F3	9.1	0	9.9
CWQI	84.2	100	90.6

International Journal of Academic Engineering Research (IJAER)
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Table 5: Canadian Water Quality Index (CWQI) of the Groundwater of Three Communities with Classification

S/N	STATIONS	DESCRIPTIONS	CWQI	Classification
1	WQA-OG	Ogbogoro	84.2	Good
2	WQA-OZ	Ozouba	100	Excellent
3	WQA-RK	Rumuokwachi	90.6	Good

Discussion

pH, turbidity, calcium, magnesium, chloride, conductivity, dissolved oxygen, sulfate, total hardness, total alkalinity, and TDS are the parameters used to calculate the CWQI. Using Equation (6), the values of parameters F1, F2, F3, and Canadian Water Quality Index (CWQI) for the groundwater of three samples are found. Furthermore, the computed values of CWQI for every location are displayed in Figure 2.

The results from the sample of the three locations indicate that Rumuokwachi and Ogbogoro have good WQI evaluations over the classification of CWQI and the mean conditions rarely deviate from natural or desirable levels but can also be used for drinking, irrigation, farming, and industry. Ozouba has an excellent WQI evaluation, meaning it can be used for these uses as well as meaning that water quality is protected with a virtual absence of threat.

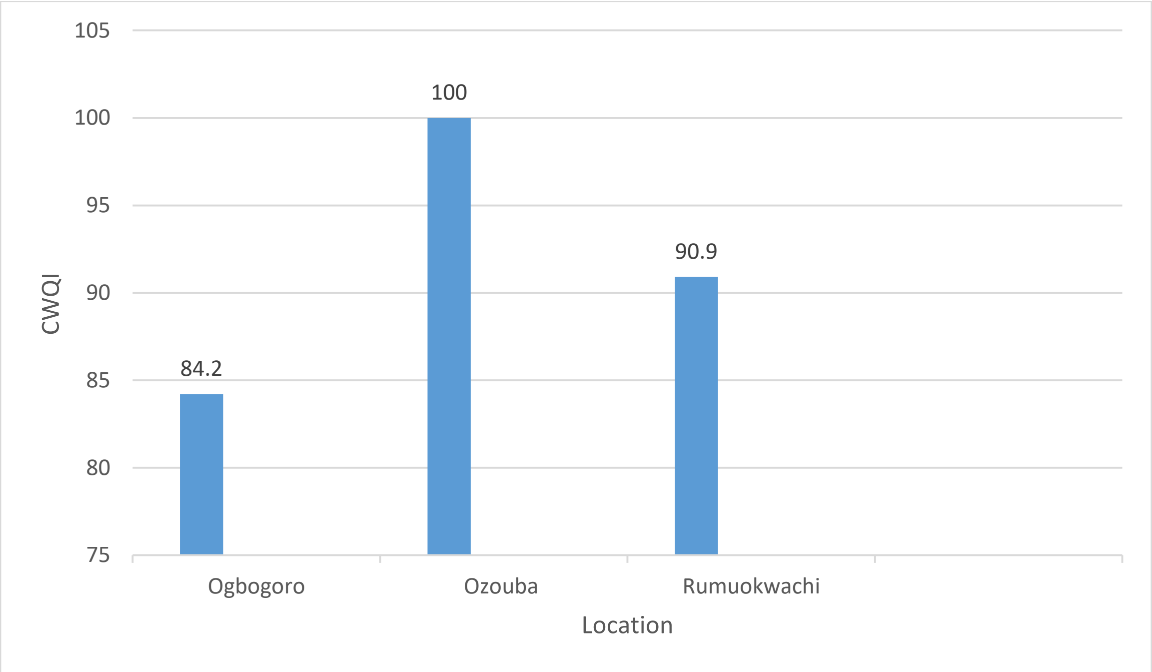

Fig. 2. *Chart Showing the Canadian Water Quality Index Result*

Assessment of Individual Hazard Groups

The structure of the water region's geological formation and external variables, including drainage practices in agriculture and other civil operations, influence the concentration of parameters that affect the quality of groundwater used for irrigation. Every study borehole in this research is situated in Ozuoba.

Sodium Hazard

Due to the unique negative effects of sodium on the physical characteristics of soil, the risk associated with this element is given particular consideration. Sodium absorption ratios, or SARs, are commonly used to express sodium risk. The ratio of sodium (Na) to calcium (Ca) and magnesium (Mg) ions in a water sample is measured by this index. Soil structure can be deteriorated by irrigation water containing high salt concentrations. This will limit aeration and decrease water infiltration into the soil's surface and profile, which will lower crop development. The contents of Na, Ca, and Mg are expressed in (mg/l).

The spatial and temporary values of SAR are presented in Table 3. The values of SAR in the study samples ranged from 37.50 mg/I to 71.50mg/I. Table 3 indicates that the mean values of SAR for the samples are within the standard limits of SAR while it is less than the permissible limit 200 mg/I. Generally, the groundwater of all wells is safe from SAR hazard for irrigation purposes.

Chloride Hazard

The second parameter that defines the particular ion toxicity is chloride concentrations. All of the wells' chloride concentrations range from 68.30 mg/l to 97.60 mg/l. The groundwater samples have lower levels of chloride than the 250 mg/l allowable standard value. Consequently, there are no chloride threats to the groundwater samples. Therefore, using this water directly for irrigation is acceptable.

Bicarbonate Hazard

Plant health may be negatively impacted by irrigation water containing high bicarbonate concentrations. The findings of the laboratory measurements of the bicarbonate content in each water sample in the research area are displayed in Table 5. The groundwater samples exhibit a range of bicarbonate values, from 30.40 mg/l to 117.0 mg/l. The groundwater samples have lower levels of bicarbonate than the 1000 mg/l permitted standard limit. Consequently, there are no bicarbonate risks present in the groundwater of the samples.

pH Hazard

The Hydrogen Power One of the key elements that functions as a pollution index is pH. Table 3 illustrates the typical pH range of irrigation water, which is 6.5 to 8.4. The samples' groundwater had pH values ranging from 6.55 to 6.76.These findings suggest that groundwater generally has a neutralizing tendency. The average observed pH values for every sample fall within the range of acceptable standard pH values. Well groundwater is therefore secure from pH issues.

4. CONCLUSION

The Canadian Water Quality Index (CWQI) was used in this study to assess the groundwater quality in the Ozuoba Obio/Akpor local government area. The following conclusions were drawn in light of the results of the water quality index that were obtained:

i. The CWQI values for Ozuoba and Ogbogoro and Rumuokwachi are outstanding and good, respectively, meaning that the groundwater in all three places is appropriate for direct use for domestic and irrigation needs.

ii. A plan should be created to track any changes to the groundwater quality in the Ozuoba Obio/Akpor local government area in the future and to see how the level of pollution in the soil and water is affected by the ongoing extraction of groundwater.

iii. According to the research's findings and discussion, the groundwater of the Ozuoba Obio/Akpor local government region was examined, and both chemical and physical analyses of the water were done. The analysis's findings were contrasted with WHO drinking water guidelines. The findings align with WHO drinking water guidelines, leading to the following conclusions.

REFERENCES

[1] Sahar, E., David, I., Gelman, Y., Chikurel, H., Aharoni, A., Messalem, R., & Brenner, A. (2011). The use of RO to remove emerging micropollutants following CAS/UF or MBR treatment of municipal wastewater. *Desalination*, *273*(1), 142-147.

[2] Egbo, M. L., Bamgbose, A. M., Oyawoye, O. M., & Ngele, M. B. (2002). Effects of preservation methods on the nutritional qualities of milk and some milk products. *Nigerian Journal of Animal Science*, *5*(1).

[3] McCahill, L. E., Single, R. M., Bowles, E. J. A., Feigelson, H. S., James, T. A., Barney, T., ... & Onitilo, A. A. (2012). Variability in reexcision following breast conservation surgery. *Jama*, *307*(5), 467-475.

[4] Braunstein, J. (2007). Trading the Rain: Should the World's Fresh Water Resources be an Internationally Traded Commodity? In *Integrated water resources management and security in the Middle East* (pp. 269-281). Springer Netherlands.

[5] Xia, X., Yang, Z., & Wu, Y. (2009). Incorporating eco-environmental water requirements in integrated evaluation of water quality and quantity—a study for the Yellow River. *Water resources management*, *23*, 1067-1079.

[6] Holmes, K. K., Sparling, P. F., Stamm, W. E., Piot, P., Wasserheit, J. N., Corey, L., ... & Nelson, R. A. (2007). *Sexually transmitted diseases*. McGraw-Hill.

[7] Udom, G. J., Ushie, F. A., Esu, E., Oofojekwu, P. C., Ezenwaka, I. S., & Alegbeleye, W. O. (2002). A geochemical survey of groundwater in Khana and Gokana Local Government Areas of Rivers State, Nigeria. *Journal of Applied Sciences and Environmental Management*, *6*(1), 53-58.

[8] Nobumasa, T. (2006). A bronchial glomus tumor surgically treated with segmentation. *Interact Cardiovasc Thorac Surg*, *5*, 258-260.

[9] Chiedozie, O., & Tosan, A. O. (2022). Groundwater Quality around Active and Non-Active Dumpsites in Benin City, Nigeria.

[10] Cioffi, F., Christina, K., Upmanu, L., & DI GIAMBERARDINO, P. (2009). Projections of climate extremes under potential climate change as represented by changing equator to pole temperature gradient and land ocean temperature contrast. In *AGU2009 S. Francisco*.

[11] Dokka, R. K. (2011). The role of deep processes in late 20th century subsidence of New Orleans and coastal areas of southern Louisiana and Mississippi. *Journal of Geophysical Research: Solid Earth*, *116*(B6).

[12] Ford, A., Casey, V., Goverde, R., Newton-Lewis, V., MacDonald, A., Upton, K., & Pole, H. (2022). Groundwater: the world's neglected defence against climate change.

[13] Lopez, O. L., Kuller, L. H., Fitzpatrick, A., Ives, D., Becker, J. T., & Beauchamp, N. (2003). Evaluation of dementia in the cardiovascular health cognition study. *Neuroepidemiology*, *22*(1), 1-12.

[14] Atekwana, E. A., Atekwana, E. A., Rowe, R. S., Werkema Jr, D. D., & Legall, F. D. (2004). The relationship of total dissolved solids measurements to bulk electrical conductivity in an aquifer contaminated with hydrocarbon. Journal of Applied Geophysics, 56(4), 281-294.

[15] Singh, J. A., Furst, D. E., Bharat, A., Curtis, J. R., Kavanaugh, A. F., Kremer, J. M., ... & Saag, K. G. (2012). 2012 update of the 2008 American College of Rheumatology recommendations for the use of disease-modifying antirheumatic drugs and biologic agents in the treatment of rheumatoid arthritis. *Arthritis care & research*, *64*(5), 625-639.

[16] Bodoczi, A., & Carpa, R. (2010). The quantitative variation of some ecophysiological group of bacteria from Arieş River sediments affected by pollution. *Carpathian Journal of Earth and Environmental Sciences*, *5*(2), 145-152.

[17] Cookey, P. E., Darnsawasdi, R., & Ratanachai, C. (2016). Performance evaluation of lake basin water governance using composite index. *Ecological indicators*, *61*, 466-482.

[18] Akpoveta, V. O., Osakwe, S., Egharevba, F., Medjor, W. O., Asia, I. O., & Ize-Iyamu, O. K. (2012). Surfactant enhanced soil washing technique and its kinetics on the remediation of crude oil contaminated soil. *Pac J Sci Technol*, *13*(1), 443-456.

[19] Abbaspour, K., Matta, V., Huggenberger, P., & Johnson, C. A. (2000). A contaminated site investigation: comparison of information gained from geophysical measurements and hydrogeological modeling. *Journal of contaminant hydrology*, *40*(4), 365-380.

[20] Oteri, A., Salvo, F., Caputi, A. P., & Calapai, G. (2007). Intake of energy drinks in association with alcoholic beverages in a cohort of students of the School of Medicine of the University of Messina. *Alcoholism: Clinical and Experimental Research*, *31*(10), 1677-1680.

[21] Saffran, J. R. (2001). Words in a sea of sounds: The output of infant statistical learning. *Cognition*, *81*(2), 149-169.

[22] Nocedal, J., & Wright, S. J. (Eds.). (1999). *Numerical optimization*. New York, NY: Springer New York.

[23] Lumb, A., Halliwell, D., & Sharma, T. (2006). Application of CCME Water Quality Index to monitor water quality: A case study of the Mackenzie River basin, Canada. *Environmental Monitoring and assessment*, *113*, 411-429.

[24] Suthra, S., Bishnoi, P., Singh, S., Mutiyar, P. K., Nema, A. K., & Patil, N. S. (2009). Nitrate contamination in groundwater of some rural areas of Rajasthan. *Department of Civil Engineering, Indian Institute of Technology New Delhi India*, 111-135.

[25] Liou, S. M., Lo, S. L., & Wang, S. H. (2004). A generalized water quality index for Taiwan. *Environmental monitoring and assessment*, *96*, 35-52.

[26] Tsegaye, T., Sheppard, D., Islam, K. R., Tadesse, W., Atalay, A., & Marzen, L. (2006). Development of chemical index as a measure of in-stream water quality in response to land-use and land cover changes. *Water, Air, and Soil Pollution*, *174*, 161-179.

[27] Arimieari, L.W., Egop, S.E., Eneawaji, U.A., & Joseph, A. E. (2024). Assessment of Groundwater Quality in Asarama, Andoni Local Government Area, Rivers State. Journal of Environmental Engineering and Its Scope, 7(2), 1–12.

[28] Sargaonkar, A., & Deshpande, V. (2003). Development of an overall index of pollution for surface water based on a general classification scheme in Indian context. *Environmental Monitoring & Assessment*, *89*(1).

[29] WHO (2005): Guidelines for Drinking Water quality vol. WHO press, Geneva, Switzerland.

[30] UNEP GEMS/Water Programme (2007). Global Drinking Water Quality Index Development and Sensitivity Analysis Report. National Water Research Institute. Burlington, Ontario, L7R 4A6 Canada

[31] WHO (2006): Guidelines for Drinking Water Quality (3rd ed.). Volume 1 A.I.T.B.S Publishers and Distributors. (Redg). Dehli Adetunde L.A., Glover R.I.K. and Oguntola G.O. (2011). Assessment of the groundwater quality