Ilorin Journal of Science
Volume 7, Number 1, 2020, pp. 83 – 95 (Printed in Nigeria)
ISSN: 2408 – 4840 © 2020 Faculty of Physical Sciences, University of Ilorin
https://doi.org/10.54908/iljs.2020.07.01.006

ILORIN
JOURNAL OF SCIENCE

ILJS-20-016

Assessment of the Suitability of Groundwater Systems for Irrigation Purposes in Owerri and Environs, Southeastern Nigeria.

Amadi[*1], A. N., Umeugochukwu[2], O. P., Unuevho[1], C. I., Waziri[1], N. M., Onoduku[1], U. S. and Ameh[1], I. M.

[1]Department of Geology, Federal University of Technology, Minna, Niger State.
[2]Department of Soil Science and Land Management, Federal University of Technology, Minna, Niger State.

Abstract
Groundwater quality evaluation for irrigation purposes in Owerri and Environs, Southeastern Nigeria was the sole aim of this research for enhancing effective agricultural production. The study area consists of prolific unconfined aquifer belonging to the continental Benin Formation of Oligocene age. Fourty-two groundwater samples were collected under standard conditions from Owerri and environs and sent to laboratory for analysis. The results of the physical parameters (pH 5.50 – 7.80, electrical conductivity 70.50 – 805.20 and total dissolved solids 42.40 – 580.60) fall within the permissible limit for good irrigation water. The laboratory results of the major ions whose concentrations were milligram per litre are converted to milliequivalent per litre and used to compute the irrigation quality indices. The sodium adsorption ratio (SAR) ranged from 0.10 – 7.85 meq/L with a mean value of 1.40 meq/L while the concentration of soluble sodium percentage (SSP) varied from 3.75 – 26.70 meq/L with an average value of 10.80 meq/L. The concentration of plasticity index (PI) ranged from 15.80 – 60.50 meq/L with a mean value of 35.20 meq/L while the value of residual sodium bicarbonate (RSBC) varied from 0.95 – 2.10 meq/L with an average value of 1.15 meq/L. The value of Kelly ratio (KR) varied from 0.02 – 0.58 meq/L with a mean value of 0.25 meq/L while magnesium adsorption ratio (MAR) ranged from 4.50 – 52.50 meq/L with an average value of 20.10 meq/L. Based on the results of irrigation index parameters analyzed, groundwater systems in the area are suitable for irrigation purposes. The salinity plots, permeability plots and Wilcox diagram further attest that the groundwater systems in the area are suitable for irrigation purposes. It is recommended that groundwater in the area should be harnessed for dry season farming in the area so as to boast food production in the area.

Key words: Unconfined Aquifer, Benin Formation, Quality Parameters, Irrigation Plots, Food Production.

1. Introduction

Water quality analysis is one of the most important aspects in groundwater studies and the quality of water determines its suitability for domestic, irrigational and industrial purposes. Chemical analysis forms the basis of interpretation of the quality of water in relation to the

*Corresponding Author: Amadi, A. N.
Email: an.amadi@futminna.edu.ng

source, geology, climate and intended use (Amadi *et al*., 2014). Water is an excellent solvent and it is important to know the geochemistry of the dissolved constituents. Contaminants enter groundwater from sources at the ground surface through chemical weathering, soil leaching, mining, decaying vegetation and leachate from dumpsites. These processes depend on the geological and geochemical conditions, as well as the chemical and biological characteristics of the contaminant. Studies revealed that the chemical composition of groundwater is affected by several factors such as topography, rock and soil compositions, rainfall pattern and temperature in the region, soil microbial diversity, land use pattern and anthropogenic processes. The natural chemistry of groundwater is largely controlled by the dissolution of the geologic materials through which the water flows. The fate of chemical constituents in the groundwater is determined by their reactivity and migration capacity from the soil (Amadi *et al*., 2019).

The chemical composition of water determines whether it can be used for irrigational purposes without deleterious effects. Studies by Helena *et al*. (2000) and Amadi *et al*. (2016a) have shown that the parameters affecting the suitability of water for irrigation purposes are electrical conductivity (EC), soluble sodium percentage (SSP), total dissolved solids (TDS), sodium adsorption ratio (SAR), magnesium adsorption ratio (MAR), permeability index (PI), Kelly's ratio (KR) and residual sodium bicarbonate (RSBC).

The prolonged use of certain irrigation water results in reduced yields due to deterioration in the soil physical properties caused by the water quality used for irrigation. The adverse effects of irrigation water quality on soil physical properties is associated with the accumulation of sodium ion on the soil exchange complex, which imparts instability to the soil aggregates and this is followed by dispersion of clay particles resulting in clogging of soil pores. The water quality used for irrigation is very essential for the quality, yield and quantity of crops produced, maintenance of soil productivity and protection of the environment (Nwankwoala and Amadi, 2013). At the same time, the quality of irrigation water is very much influenced by the geochemistry and geology of the water source (Amadi *et al*., 2014). According to Lambarkis (2004), the chemical constituents that affect the suitability of water for irrigation purposes include: total concentration of soluble salts, concentration of boron, relative proportion of sodium to calcium and magnesium as well as relative proportion of bicarbonate to calcium and magnesium.

In terms of agricultural purposes, sodium adsorption ratio (SAR) is the most useful parameter. Sodium is introduced into the aquifer in the area through infiltration and bed-rock dissolution processes (Nwankwoala *et al.,* 2020). Due to its effects on soils and plants, sodium is considered one of the major factors governing irrigation water (Offodile, 2012). Dry season farming in the Southeastern Nigeria is a problem due to scarcity of water. All farming activities are highly dependent on rain fed agriculture. There was a serious yellowing and retarded growth of plants as rain seized abruptly for more than three weeks in August, 2020, in what is known as ‘August Break’. Hence, the assessment of suitability of ground water for irrigation is necessary to supply for irrigation purposes in situations of no rain. Based on the quality attributes, surface and groundwater can be used for drinking, domestic, irrigational, agricultural and industrial purposes. Suitability of water for irrigation is based on the sodium adsorption ratio (SAR) and other index parameters. The objectives of this study therefore to assess the suitability of groundwater system of Owerri Metropolis for irrigation purposes. The study will specifically investigate the water quality indicators for irrigation in the study area.

Study Area Description

The study area lies within Owerri and Environs, Southestern Nigeria. It lies between latitude 5º15′N to 5º40′N and longitude 6º55′E to 7º15′E (Figure 1). The area has a good road network and is accessed through Aba, Onitsha, Orlu, Okigwe and Port-Harcourt roads (Ibe *et al*., 2018; Figure 1). The prevalent climatic condition in the area comprises of the rainy (March to October) and dry (November to February) seasons characterized by high temperatures, low pressure and high relative humidity throughout the year (Ezeigbo, 1989). The mean annual temperature of 32ºC is common for the area (Ibe *et al*. 1992; Ngah, 2002).

Geology and Hydrogeology of the Study Area

The study area is outcropped by the Benin Formation, which consists of sands, sandstone and gravel with clay occurring in lenses (Figure 2). It is made up of fresh water bearing sands and fine-gravel. The sandy formation which constitutes about 95% of the rock in the area is composed of over 97% of quartz (Onyeagocha, 1980). Groundwater occurs in abundance in Benin Formation as the aquifer is highly prolific based on the results of the computed hydraulic conductivity, permeability, aquifer yield, transmissivity and storage coefficient. Groundwater is in constant interaction with the host rock in the course of its movement through the pore spaces for sedimentary rock or fractures/weathered zone for crystalline rocks (Amadi *et al*., 2020).

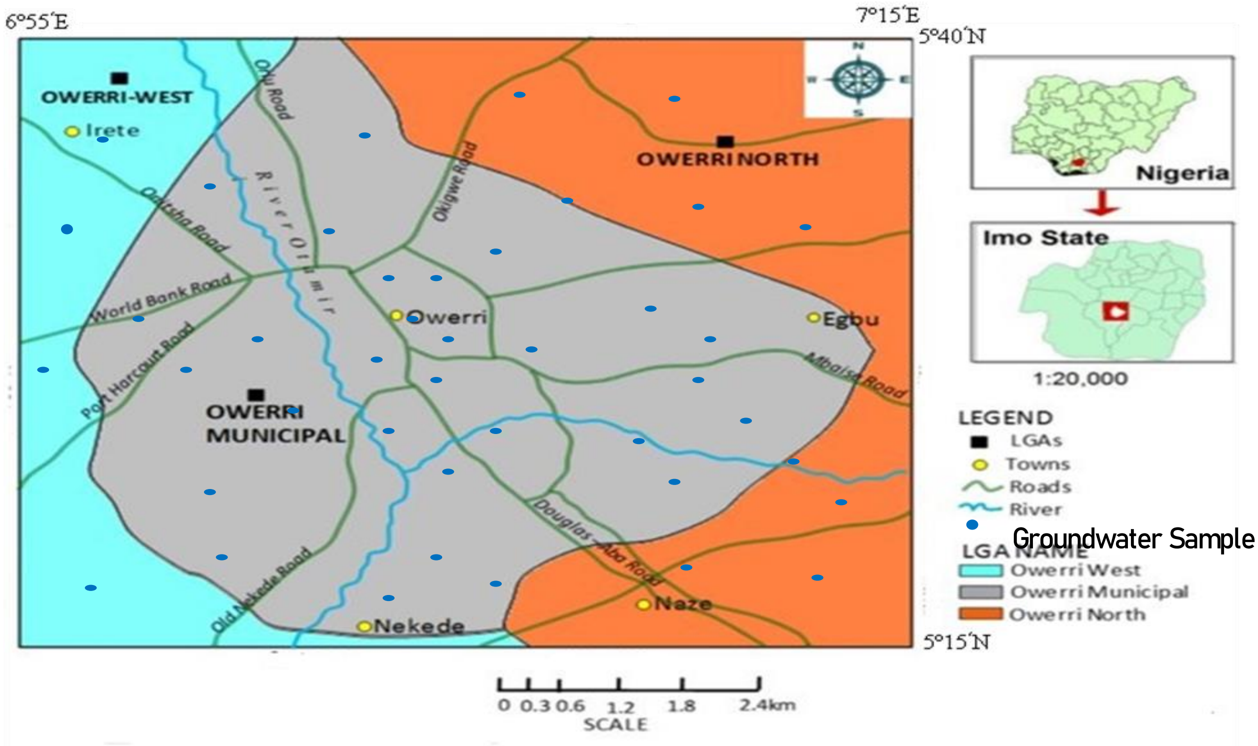

Figure 1: Map of the Study Area showing the road network and drainage system (Modified after Ibe *et al*., 2018).

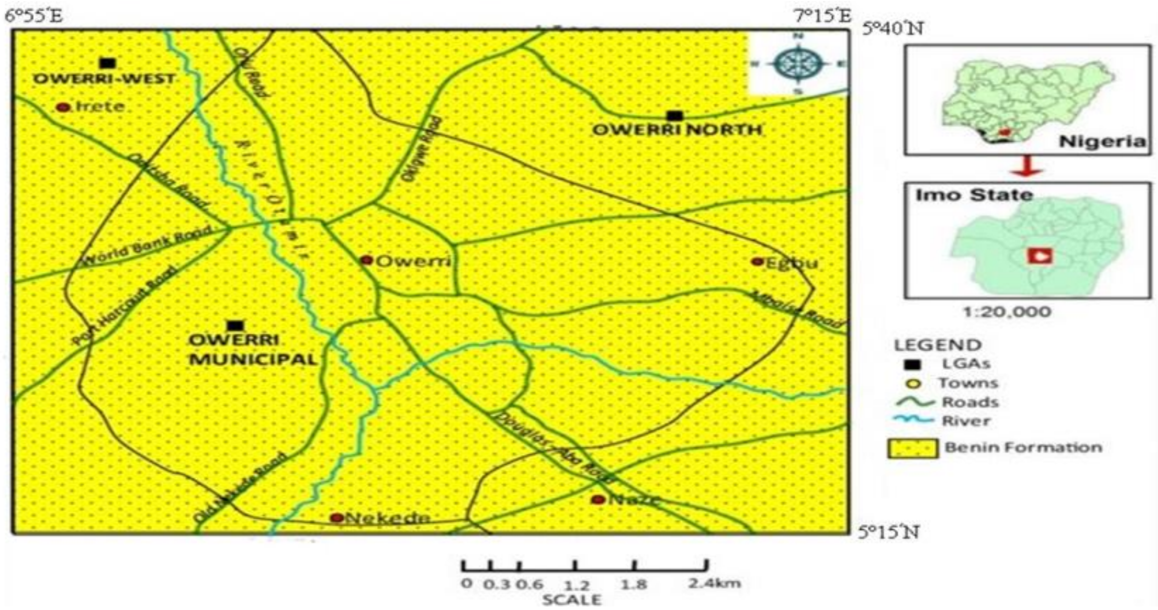

Figure 2: Geology Map of Owerri and Environs (Modified after Ibe *et al*., 2018).

2. Materials and Methods

2.1 Sample Collection

A total of 42 groundwater samples (Figure 1) were collected in acid-washed polyethylene 500 ml bottle across the study area and suitable preservative were added for storage till completion of quantitative chemical analysis. Physical parameters such as pH, electrical conductivity, and total dissolved solids values were determined in-situ using HI9811-5 Portable pH/EC/TDS/ºC Meter by Hanna Instruments. The bottles were completely filled with water taking care that no air bubble was trapped within the water sample. Then to prevent evaporation, the bottles were sealed with double plastic caps and precautions were taken to avoid sample agitation during transfer to the laboratory in accordance with AOAC standard (1990). The samples were immediately transferred to the laboratory.

Laboratory Analysis

Samples were analyzed in the laboratory for the major ionic concentrations employing standard methods. Calcium and magnesium were determined titrimetrically using standard EDTA, chloride by standard $AgNO_3$ titration, bicarbonate by titration with HCl while sodium and potassium were determined through flame photometry. Sulphate and phosphate were determined by spectrophotometer CL 22D while nitrate and fluoride concentration were obtained using ion selective electrode. The analytical precision for the major ions was determined by the ionic balance calculated from 100*(cations – anions) ÷ (cations + anions) and the value obtained was ±3.5% which falls within the acceptable limit of ±5% in accordance with APHA (1995).

Irrigation Quality Index

In order to achieve the objective of the research, the concentration of the major cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and anions (CO_3^{-}, HCO_3^{-}, SO_4^{2-} and Cl^{-}) were converted from milligram per litre (mg/L) to milliequivalent per litre (meq/L) and used to compute the irrigation index parameters. Groundwater suitability for irrigation purpose in this study was assessed through: sodium adsorption ration (SAR), magnesium adsorption ratio (MAR), soluble sodium percentage (SSP), residual sodium carbonate (RSBC), permeability index (PI), Kelly ratio (KR), total dissolved solids (TDS), electrical conductivity (EC) and pH. The results are expressed in meq/L except pH, EC and TDS.

3. Result and Discussion

3.1 Water Quality Analysis

pH

Good quality irrigation water is essential for achieving maximum crop productivity. The pH is an important indicator of water quality for irrigation as it influences the rate at which plants take up nutrients from the soil. The pH value ranged from 5.50 and 7.90 with a mean value of 6.85 (Table 1). The observed slightly low pH in the regions can be attributed to the age long impact of gas flaring and oil spills in the near-by Ohaji/Egbema oil producing communities. This practice over the years has led to the problem of acid-rain, a situation where NO_2, SO_2 and CO_2 associated with gas flaring reacts with water molecules (H_2O) in the atmosphere to form weak acids such H_2NO_3, H_2SO_3 and H_2CO_3 (Amadi, 2014). It also accounts for the rusting of roofing sheets in the area. When the rain water infiltrates through the porous and permeable unconfined aquifer (Benin Formation), into the shallow water table, the groundwater system is deteriorated.

3.2 Electrical Conductivity (EC)

This is the ability of water to conduct electrical current and it is a function of the amount of dissolved solutes in water. The EC is a useful parameter in categorizing salinity hazard as well as suitability of water for irrigation purposes. The EC concentration varied from 40.50 µs/cm^3 to 808.20 µs/cm^3 with an average value 250.10 µs/cm^3 (Table 1). High concentration of sodium in water or soil is detrimental to plants. According to Freeze and Cherry (1979) water with EC greater than 2,250 µs/cm^3 is unsuitable for irrigation purpose (Table 2) and the analyzed groundwater samples from the study area are within good to excellent range. Irrigation water having high EC content will affect root area and water flow in crops.

3.3 Total Dissolved Solid (TDS)

This is another important irrigation quality parameter and the concentration of TDS ranged from 18.40 mg/L to 565.80 mg/l with a mean value 195.00 mg/L (Table 1). It is a measure of the combined content of all inorganic and organic substances present in water. The TDS values (<1000) are very good for irrigation water (Table 2) and will not affect the osmotic pressure of the soil solution (NSDWQ. 2017).

3.4 Irrigation Index Parameters

Sodium Adsorption Ratio (SAR)

It is a measure of the sodicity of the soil and provides vital information about the adsorption of sodium by soils (Richard, 1954). The SAR was calculated in meq/L using the formula.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (1)$$

Excess absorption of sodium can cause sodium toxicity in plants, causing marginal leaf burn on older foliage and possibly defoliation. Water containing excessive amount of sodium may immobilize other nutrient ions particularly calcium, magnesium and potassium, which can result in deficiencies of these elements in plants. The adverse effect of sodium to the soil is a function of the ratio of sodium to the total cations in the irrigation water. When water used in irrigation is high in Na^{+} and low in Ca^{2+}, the cation exchange complex may become saturated with Na. This can destroy the soil structure owing to dispersion of clay particles. The calculated SAR (Table 1) for the groundwater ranged from 0.01 – 7.85 meq/L with a mean value of 1.40 meq/L. The data show that the samples fall in S1 (Figure 3), indicating low salinity and low Na^{+} water. This implies that for irrigation purposes, there no fear that the soils and crops will develop exchangeable sodium and salinity, confirming the fact that water from the study area is good for irrigation. Also, according to Michael (1978), SAR values below 10 meq/L is good for irrigation. High SAR values (>10) can cause sodium to replace adsorbed calcium or magnesium, thereby damaging the soil structure. Richards (1954) classified the concentration of soluble salt in irrigation water (salinity hazard) into four classes on the basis of EC and SAR (Table 2). Groundwater with high EC leads to formation of saline soil while high Na^{+} leads to development of an alkaline soil (Olasehinde *et al*., 2015; Amadi *et al*., 2016b; Etu-Efeotor and Odigi, 1983).

Table 1: Descriptive Statistics of Irrigation Quality Parameters.

Parameters	**Minimum**	**Maximum**	**Mean**
SAR (meq/L)	0.01	7.85	1.40
SSP (%)	3.75	26.70	10.80
PI (%)	15.80	70.50	46.20
RSBC (meq/L)	0.95	2.10	1.15
MAR %	14.30	52.60	20.10
KR (meq/L)	0.02	0.58	0.25
EC (µs/cm^{3})	40.50	808.20	250.10
TDS (mg/L)	18.40	565.80	195.00
pH	5.50	7.90	6.85

Table 2: Index Parameters Ranking of Irrigation Water (After Richards, 1954; Johnson, 1975; Ayers and Westcot, 1994; Amadi *et al*., 2019).

Category	EC (µS/cm)	TDS (mg/l)	SAR (meq/L)	SSP (%)	PI (%)	Remark
I	<250.0	<500.0	<10.0	<20.0	<80.0	Excellent
II	250.0-750.0	500.0-1000.0	10.0-18.0	20.0-40.0	80.0-100.0	Good
III	750.0-2250.0	1000.0-3000.0	18.0-26.0	40.0-80.0	100.0-120.0	Fair
IV	2250.0-5000.0	>3000.0	>26.0	>80.0	>120.0	Unsuitable

EC - Electrical Conductivity; TDS - Total Dissolved Solids; SAR - Sodium Adsorption Ratio; SSP - Soluble Sodium Percentage; PI - Permeability Index

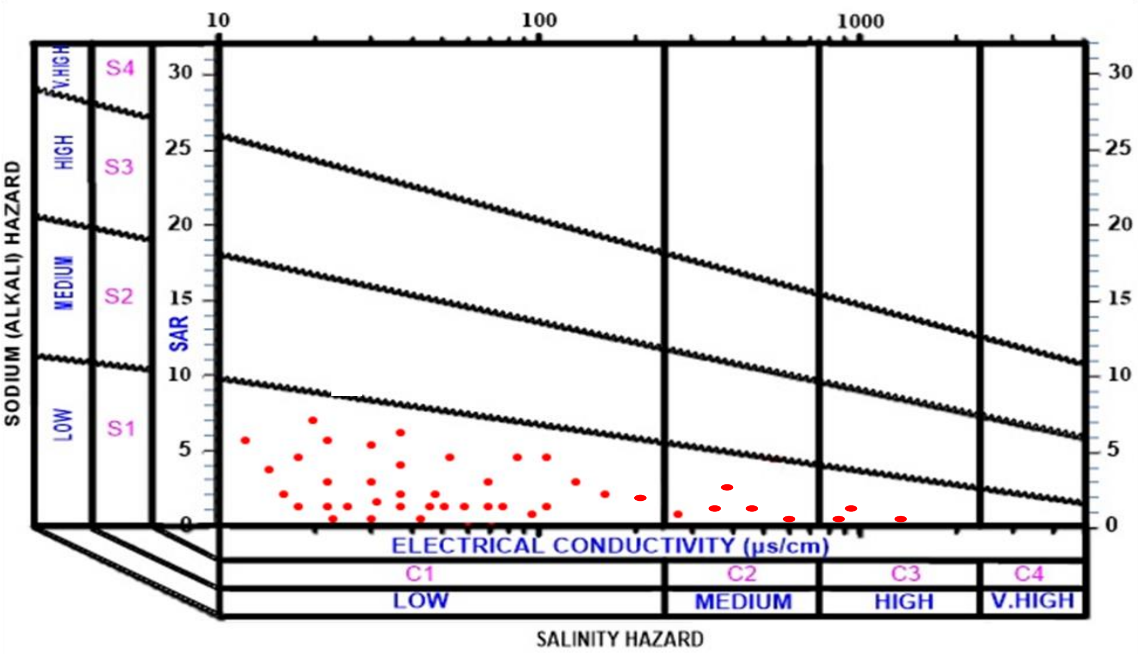

Figure 3: The Salinity Hazard Diagram for the Study Area.

3.5 Soluble Sodium Percentage (SSP)

High sodium ion concentration in soil can take a toll on internal drainage patterns in soil. The SSP was determined in this study using the Wilcox formula postulated in 1950 and the concentrations are expressed in meq/L.

$$SP = \frac{(Na^{+} + K^{+})}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \times 100 \quad (2)$$

The concentration of SSP ranged from 3.75 % to 26.70 % with a mean value of 10.80 % (Table 1). When the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing magnesium and calcium ions. The exchange process of sodium in water for magnesium and calcium in soil reduces permeability and eventually results in soil with poor drainage. The air and water circulation is restricted during wet conditions and such soils are usually hard when dry. It is neither adsorbed nor held back by soil particles, rather it moves readily with the soil-water and gets adsorbed by crops and accumulates in the leaves leading to the development of symptoms such as leave burn and drying of tissues. The Wilcox plot (Figure 4) indicates that the groundwater in the study is is averagely low in sodium and electrical conductivity, which is in conformity with the salinity hazard plot (Figure 3). Groundwater with low concentration of SSP (< 80.0 %) is suitable for irrigation (Class I, II and III of Table 2).

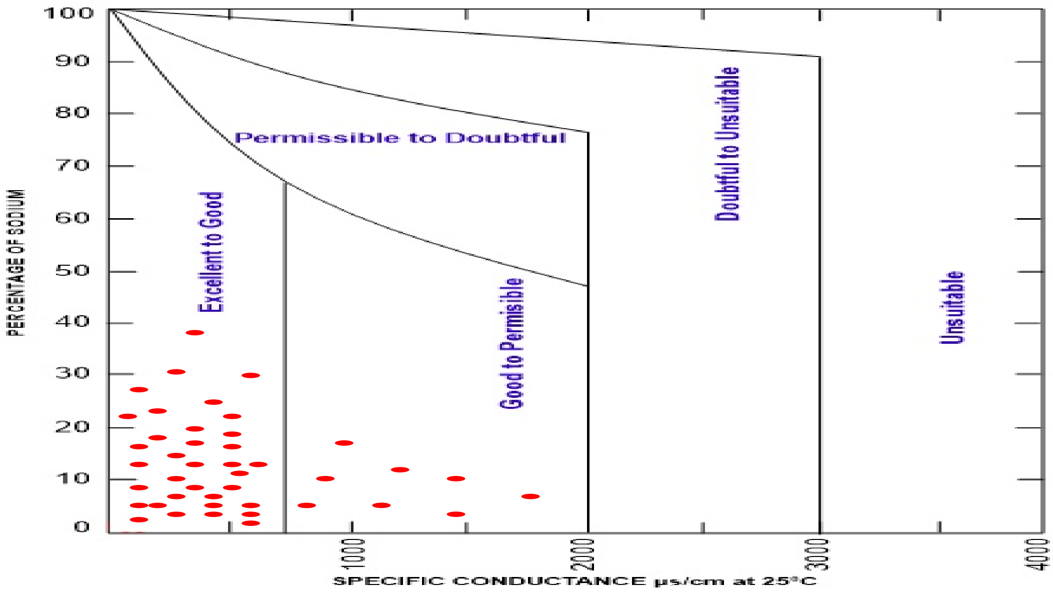

Figure 4: Wilcox Diagram for the Study Area.

Table 3: Classification of Irrigation water based on MAR and KR Values (Wilcox, 1955).

Class	MAR (%)	KR (meq/l)	Irrigation Rating
I	<50.0	<1.0	Suitable
Ii	>50.0	>1.0	Unsuitable

MAR – Magnesium Adsorption Ratio; KR – Kelly's Ratio

3.6 Residual Sodium Bicarbonate (RSBC)

When the concentration of bicarbonate and carbonate in water is higher than calcium and magnesium, the suitability of the water for irrigation purposes will be deteriorate. The RSBC value was computed using the formula and the ions were expressed in meq/l.

$$RSBC = (HCO_3^- + CO_3^-) - (Ca^{2+} + Mg^{2+}) \quad (3)$$

The computed RSBC value ranged from 0.95 meq/l to 2.10 meq/l with an average value of 1.15 meq/l. These values also confirm with findings that the groundwater in the area is suitable for irrigation. An excess of $HCO_3^-$and CO_3^- ions in water reacts with Na^+ in soil resulting in a sodium hazard. The water with high RSC has high pH and land irrigated by such water becomes infertile owing to deposition of sodium carbonate as indicated by the black color of the soil. According to Eaton (1950) and Amadi *et al*. (2016), RSBC values less than 1.25 meq/L are termed good to excellent for irrigation, between 1.25 to 2.50 meq/L are fairly good/marginal while water whose RSBC values are greater than 2.50 are not suitable for irrigation.

3.7 Permeability Index (PI)

Another useful index in determining the suitability of water for irrigation is permeability index. Soil permeability is affected by the long term use of irrigation water and is a function of total dissolved solids, sodium contents and bicarbonate content. In order to incorporate these three parameters, Doneen (1964) developed an empirical formula called 'Permeability Index' after conducting a series of tests and experiments for which he had used a large number of irrigation waters varying in ionic relationships and concentration in meq/L is given as:

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}} X100}{(Ca^{+} + Mg^{+} + Na^{+})} \quad (4)$$

The permeability index values ranged from 15.80 % to 70.50 % and a mean value of 46.20 % (Table 1). Water can be classified as Class I, II and III with regard to permeability index (Figure 5). Class I and II are categorized as good for irrigation with 75 % or more permeability while class III is unsuitable with 25 % or less permeability (Donnen, 1964). The Donnen's permeability chart revealed that the groundwater in the study area is good for irrigation. It validates the earlier findings from the geology and hydrogeology of the area (Figure 2), as well as the salinity hazard plots (Figure 3) and Wilcox diagram (Figure 4).

3.8 Magnesium Adsorption Ratio (MAR)

In most naturally occurring water such as groundwater, the Ca^{2+} and Mg^{2+} maintain a state of equilibrium. During equilibrium as the pH increases, more Mg^{2+} in groundwater adversely affects the soil quality rendering it alkaline which result in decrease of crop yield. The magnesium adsorption ratio (MAR) are expressed in meq/L using the formula:

$$MAR = \frac{Mg^{2+} \text{ x } 100}{Mg^{2+} + Ca^{2+}} \quad (5)$$

The MAR in the groundwater varied from 14.30 % to 52.60 % with a mean value of 21.10 % (Table 1). These values are within the threshold values of good irrigation water (Table 3).

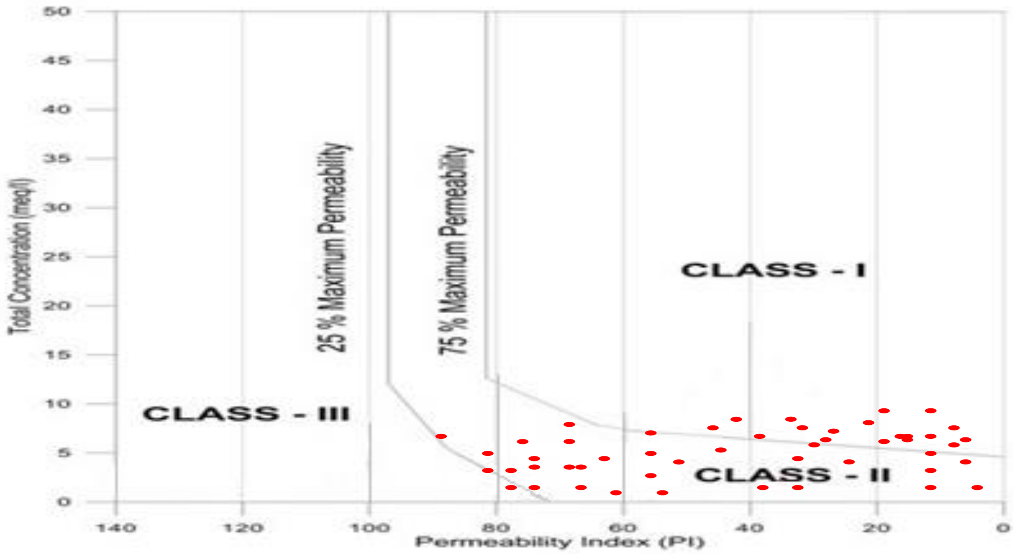

Figure 5: Doneen's Permeability Index Chart for the study area.

3.8 Kelly's Ratio (KR)

The Kelly's ratio used to rate irrigation water is measured as the level of Na against Ca and Mg. The formula is given as:

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad (6)$$

The value of KR is of the order of 0.02 – 0.56 meq/L with a mean value of 0.25 meq/L. According to Kelly, (1940), irrigation water are classified into two and water with KR value less than one, are suitable for irrigation while waters having KR values greater than one are termed unsuitable for irrigation (Table 3). Considering the results contained in Table 1, the groundwater samples from the study area are good irrigation waters. The recalculated irrigation quality parameters were found to be within the permissible limit for water meant for irrigation activity.

4 Conclusion

The quality of groundwater in Owerri and environs, Southeastern Nigeria has been assessed for irrigational purposes in this study. Based on the irrigation water quality indicators assessed, the electrical conductivity values and the total dissolved solids values of the groundwater samples are within the acceptable limit for water intended to be used for irrigation. Based on the irrigation quality parameters computed (SAR, SSP, MAR, RSBC, PI and KR), the suitability of groundwater samples for irrigation in the area is very good. The plots on the salinity hazard, Wilcox diagram and Doneen's Permeability Index Chart also confirmed the suitability of the groundwater for irrigation. The consistency in the results of the irrigation index parameters confirm the fact that groundwater from the Benin Formation within Owerri area is suitable for irrigation. It should be harnessed for irrigation in order to address food security in the region.

References

Amadi, A. N**.**, Ozoji, T. M., Aweda, A. K., Chinwuko, A. I., Shaibu, I., Ovwasa, M. O. and Ibrahim, H. A. (2020): Updates on Aquifer Attributes of the Benin Formation within Eastern Niger Delta, Nigeria using Pumping Test and Hydraulic Parameters. *Minna Journal of Geosciences*. **4**(1), 37 – 51.

Amadi, A. N., Tukur, A., Dan-Hassan, M. A., Okunlola, I. A., Shauibu I., Egharevba, J. K. and Okobi, C. M. (2019): Groundwater Quality Assessment for Irrigation Purposes: A case study of Minna, Niger State, Northcentral Nigeria. *Journal of Chemical Society of Nigeria*. **44**(4), 633 – 640.

Amadi, A. N., Olasehinde, P. I., Nwadioha, I. J., Okunlola, I.A., Shaibu I. and Nwakife, C. N. (2016a): Comparative Assessment of Groundwater Suitability for Irrigation and Drinking Purposes in Agbara and Ota area of Southwestern Nigeria. *International Journal of Science for Global Sustainability*. **2**(3), 1 – 12.

Amadi, A. N., Nwankwoala, H. O., Ameh, I. M., Shaibu, I. and Okoye, N. O. (2016b): The role of Groundwater in Poverty Alleviation and Sustainable Development in Nigeria: Challenges and Opportunities. *Proceedings of the 4th International Conference of School of Science and Technology Education*. **4**(1), 127 – 139.

Amadi, A. N., Olasehinde, P. I. and Nwankwoala, H. O. (2014): Hydrogeochemistry and statistical analysis of Benin Formation in Eastern Niger Delta, Nigeria. *International Research Journal of Pure and Applied Chemistry***.** **4**(3), 327 – 338.

Amadi, A. N. (2014): Impact of Gas-Flaring on the Quality of Rain Water, Groundwater and Surface Water in Parts of Eastern Niger Delta, Nigeria**.** *Journal of Geosciences and Geomatics*. **2**(3), 114 – 119.

APHA (1995): *Standards methods for the examination of water and wastewater*. 19th Edition American Water Works Association, Washington DC.

AOAC (1990): *Official Methods of Analysis of the Association of Analytical Chemists*. Edited by Kenneth Helrich.

Aweda, A. K., Amadi, A. N., Kyari, R., Samuel, A. and Samson, B. A. (2020): Investigation of Groundwater Quality from Selected Wells in Paiko, Northcentral Nigeria. *Journal of Geography and Geology*. **12**(1), 1 – 7.

Ayers, R. S. and Westcot, D. W. (1994): Water quality for Agriculture. *FAO Irrigation and Drainage*. Paper 29, Revision 1, 1 – 186.

Doneen, I. D. (1964): *Notes on Water Quality in Agriculture*. Department of Irrigation, University of California, Davies, 48p.

Easton, F. M. (1950): Significance of Carbonate in Irrigation Water. *Soil Science*. **67**(3), 128 – 133.

Etu–Efeotor, J. O. and Odigi, M. I. (1983): Water supply problems in the Eastern Niger Delta. *Journal of Mining and Geology*. **20**(1), 182 – 192.

Ezeigbo, H. I. (1989): Groundwater quality problems in parts of Owerri, Imo State, Nigeria. *Journal of Mining and Geology*. **25** (1-2), 1 - 9.

Freeze, R. A. and Cherry, J. A. (1979): *Groundwater*. Prentice Hall Inc. Englewood Cliffs, New Jersey, 604 pp.

Helena, B., Pardo, R., Vega, M., Barrado, E., Fernandez, J. M. and Fernandez, L. (2000): Temporary evolution of ground water composition in an alluvial aquifer (Piuerga River, Spain) by Principal Component Analysis. *Water Research.* **34**, 807-816.

Ibe, K. M., Sowa, A. H. O. and Osondu, O. C. (1992): Environmental contamination and other anthropogenic impacts on Otamiri and Nworie rivers in Owerri, Nigerian. *Journal of Mining and Geology*. **28**(1), 87-91.

Ibe, F. C., Opara, A. I., Ibe, B. O. and Ichu, C. (2018): Environmental and health implications of trace metal concentrations in street dusts around some electronic repair workshops in Owerri, Southeastern Nigeria. *Environmental Monitoring and Assessment*. **25**(1), 92-99.

Kelly, W. P. (1940): Permissible composition and concentration of irrigated waters. In: *Proceedings of the ASCF66*, 607p.

Lambarkis, N., Antonakos, A. and Panagopoulos, G. (2004): The use of multi-component statistical analysis in hydrogeological environmental research. *Water Resources*. **38**(7), 1862-1872.

Michael, A. M. (1978): *Irrigation Theory and Practice.* Vikas Publishing House LTD, New Delhi, 713p.

Ngah, S. A. (2002): Patterns of groundwater chemistry in parts of the Niger Delta. *38th Annual International Conference of Nigerian Mining and Geosciences Society*. Abstract, 39p.

NSDWQ (2017): Nigerian Standard for Drinking Water Quality. *Nigerian Industrial Standard*: Abuja, Nigeria. NIS: 554, 1-14.

Nwankwoala, H. O. and Amadi, A. N. (2013): Hydro-geochemical Attributes and Quality Status of Groundwater in Port Harcourt, Eastern Niger Delta. *World Journal of Science and Technology Research*. **1**(7), 151 – 167.

Nwankwoala, H. O., Amadi, A. N., Omofuophu, E. and Ibrahim, H. A. (2020): Risk Evaluation and Modeling of Soils Contaminated with Polycyclic Aromatic Hydrocarbons (PAHs) in parts of Bonny Island, Niger Delta, Nigeria. *Annals of Civil and Environmental Engineering.* **4**(1), 15 – 26.

Offodile, M. E. (2012): Groundwater study and development in Nigeria. *Mecon Geology and Engineering Service Limited*, Jos, Nigeria, (2nd Ed.), 239-244.

Olasehinde, P. I., Amadi A. N., Dan-Hassan, M. A. and Jimoh, M. O. (2015): Statistical Assessment of Groundwater Quality in Ogbomosho, Southwest Nigeria. *American Journal of Mining and Metallurgy*. **3**(1), 21 – 28.

Onyeagocha, A. C. (1980): Petrography and depositional environment of the Benin Formation. *Nigeria. Journal of Mining and Geology*. **17**(1), 147 – 151.

Richards, I. A. (1954): *Diagonesis and Improvement of Saline and Alkali Soils*. Agricultural Handbook 60, USDA and IBH Publication Coy LTD, New Delhi, India, 99p.

Wilcox, L. V. (1950): Classification and use of irrigation waters USDA, Circular 969, Washington.