IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 17, Issue 3 Ser. I (March 2023), PP 01-11
www.iosrjournals.org

Hydrogeochemical Properties and Irrigation Indices of Groundwater from Some Communities in Obio Rivers State, Nigeria

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ABSTRACT
An assessment of the hydrogeochemical properties and irrigation water quality of groundwater in Rumuola, Rumuokwuta and Rumuigbo Communities in Rivers State, were conducted using conventional graphical methods and mathematical models. Plots of Piper trilinear diagram indicated that the groundwater in the area had [Na^+ + K^+] as the dominant cations while HCO_3^- and Cl^- were the dominant anions; the water was further classified as 60% predominantly sodium chloride type and 33% as sodium bicarbonate type. Durov and Gibbs diagrams showed that the hydrogeochemistry of the water in the areas is characterized majorly by Ion Exchange, Reverse Ion Exchange, Simple Dissolution and Rock Weathering processes. Irrigation Indices using Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) revealed that the groundwater is excellent for irrigation purposes. Similarly, classifications based on the United States Salinity Laboratory (USSL) and Wilcox diagrams suggested that the water in the study area is of excellent quality for irrigation purposes.

Key words: ***Hydrogeochemical, Irrigation Indices, Groundwater, Obio, Rumuola, Nigeria***

Date of Submission: 01-03-2023 Date of Acceptance: 11-03-2023

I. INTRODUCTION

Water plays a very vital role in promoting agricultural production and standard of human health (Raju *et al*., 2013). Overtime, we have experienced the degradation of surface and groundwater quality; and this is the resultant effect of urbanization, population growth and industrialization (Nwankwoala *et al*., 2016).

Natural causes and/or anthropogenic factors may result in the depreciation of the quality of agricultural water of irrigation (Ayers, 1977; Anikwe *et al.*, 2002).Poor quality of water for irrigation may affect crops; giving rise to the accumulation of salts in the roots as a result of any factors such as loss of permeability of the soil due to excess sodium, calcium leaching or toxic contaminants of which are either directly toxic to plants or to those that consume these plants (Rhoades, 1972; Cooper and Lipe, 1992).

Sodium gets to the aquifer from rainwater in coastal areas and/or dissolution of rock as rainwater percolates and the groundwater flows through the aquifer (Ideriah and Ikoro, 2015). As a result of effects of sodium on soil and plants; it is considered one major factor that governs the use of groundwater in irrigation (USDA, 1954; Offodili, 2002).

Groundwater is a major source of water for domestic and agricultural purposes in the study area. Anthropogenic activities are a major source of pollution in the area; with tremendous increase in waste generation due to the high population density of the area.

Thus, knowledge of the quality of groundwater in the area and its suitability for irrigation is vital in ensuring growth of healthy crops and efficiency of crop yield.

STUDY AREA

Obio-Akpor Local Government Area in Rivers State is in the coastal plain of the Eastern Niger Delta, and is located between latitudes 4˚45′ N and 4˚60′ N and longitudes 6˚50′ E and 8˚00′ E (UNEP, 2011). Temperature in the area ranges from 21.2 ˚C to 33.4 ˚C and annual rainfall is about 4,700 mm/year (UNEP, 2011). The selected communities for this study- Rumuola, Rumuigbo and Rumuokwuta communities- are located in Obio-Akpor Local Government Area.

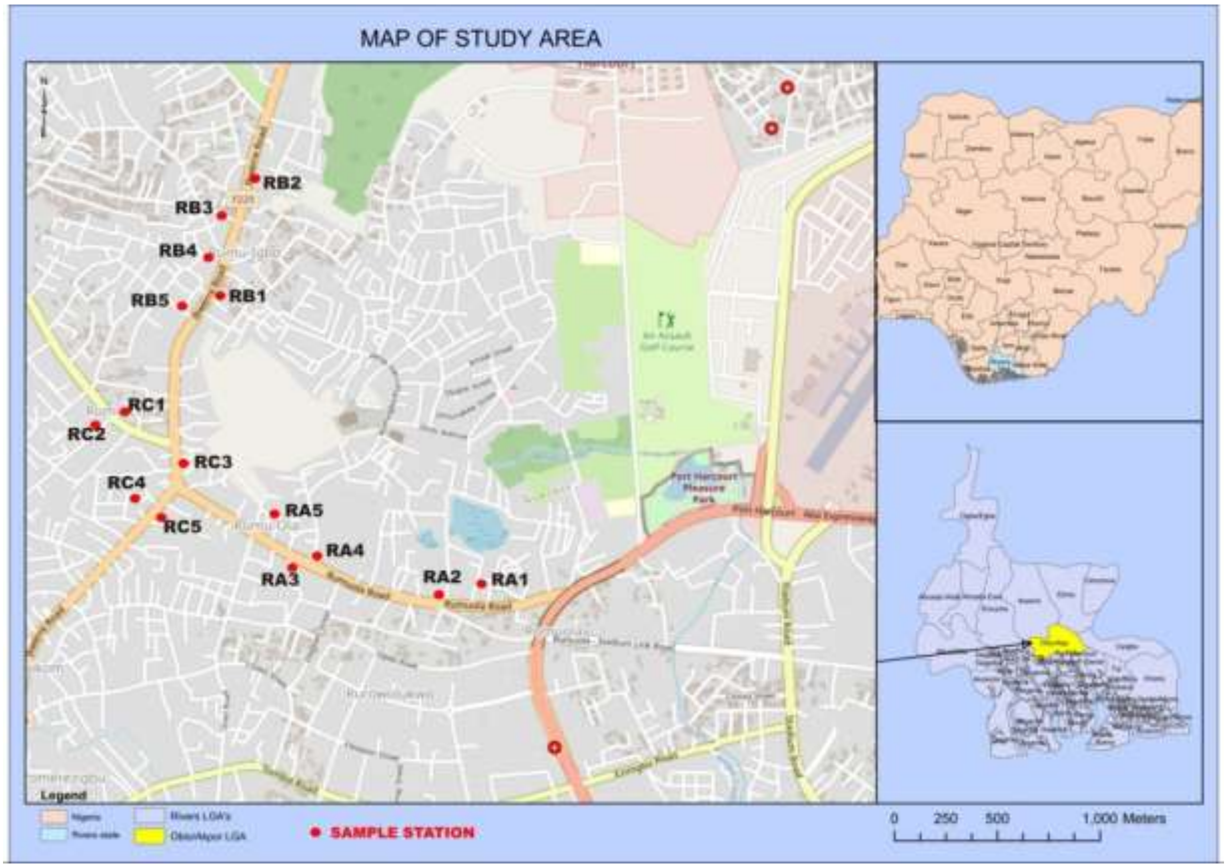

Fig.1: Map of Study Area Showing Sample Locations

II. MATERIALS AND METHODS

Sampling

Water samples were collected once a month from the fifteen sampling locations for three months (December, 2020; January and February, 2021). Samples for physicochemical analysis were collected in 1.5 litre plastic bottles. At each sampling station the water was allowed to run for about two minutes and the sample bottles thoroughly rinsed before being filled with the water from each sample station. Ice cool boxes were used to preserve and transport the samples to the laboratory for analysis.

Analytical Procedures

The pH of water was measured electrometrically usinga pH meter(Model: Mettle Delta-340, England). Electrical conductivity was measured with a JENWAY electrical conductivity meter(Model, 4010), which had been calibrated in the laboratory using standard conductivity solutions. Sodium, potassium, magnesium andsulphate ionswere determined using flame photometer. Bicarbonate was determined by the titrimetric method using naphthalene and methyl orange as indicator (Udo *et al*., 2009). Chloride was determined using the Mohr method; by reaction with silver nitrate with potassium chromate as indicator.

HYDROGEOCHEMISRY

Piper Trilinear Diagram

The Piper Trilinear Diagram evaluates the evolution of the groundwater and relationship between rock types and water composition. Plots on the Piper Trilinear Diagram reveal the composition of water in different sampling stations, indicating the water type (Piper, 1944).

Durov Diagram

Hydrochemical classifications of groundwater are governed by major ions. A Durov diagram is a useful graphical tool that is widely used to identify the chemical relationship and evolution of groundwater samples (Chen *et al.*, 2019). Durov's diagram helps to interpret the hydrochemical processes occurring in the groundwater system. Water in the study areas was plotted on the Durov diagram and classified according to Lloyd and Heathcoat (1985) as shown in Table 2.

Gibbs Diagram

The Gibbs diagram is widely used to establish the relationship of water composition and aquifer lithological characteristics (Gibbs, 1970). According to the relationship between TDS and [Na^+/ (Na^+ + Ca^{2+})]; and TDS and[Cl^-/(Cl^- + HCO_3^-)], three distinct fields such as Precipitation Dominance, Evaporation Dominance and Rock–Water Interaction Dominance areas are shown in the Gibbs diagram. Major natural factors governing groundwater formation are analyzed using Gibbs diagrams (Marghade *et al*., 2012; Naseem *et al*., 2010). The impacts of human activities on groundwater chemistry cannot be analyzed by the Gibbs diagram because of difficulty in quantifying the degree and extent of such activities (Peiyue *et al.*, 2016).

IRRIGATION INDICES

Methods for calculating the different irrigation parameters are as follows:

Sodium Adsorption Ratio (SAR): The SAR was calculated using a formula by Richards (1954).

$$\mathrm{SAR} = \frac{\mathrm{Na^+}}{\sqrt{\frac{\{\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}}\}}{2}}} \tag{1}$$

Where, Ca^{2+}, Mg^{2+} and Na^+ are concentrations in milli-eqivalent per litre (meq/L)

Soluble Sodium Percentage (SSP): The SSP was calculated using a modified formula by Todd (1980).

$$\mathrm{SSP} = \frac{\mathrm{Na^+}}{\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}} + \mathrm{Na^{2+}}} \times 100 \tag{2}$$

Where, Ca^{2+}, Mg^{2+} and Na^+ are concentrations in milli-eqivalent per litre (meq/L)

Permeability Index (PI): The PI was calculated using a modified formula by Doneen (1964).

$$\mathrm{PI} = \frac{\mathrm{Na^+} + \mathrm{HCO_3^-}}{\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}} + \mathrm{Na^+}} \times 100 \tag{3}$$

Where, Ca^{2+}, Mg^{2+}, Na^+ and HCO_3 are concentrations in milli-eqivalent per litre (meq/L)

Kelly Ratio (KR): The KR was calculated using a formula by Kelly (1940)

$$\mathrm{KI} = \frac{\mathrm{Na^+}}{\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}}} \tag{4}$$

Where, Ca^{2+}, Mg^{2+} and Na^+ concentrations in milli-eqivalent per litre (meq/L)

Residual Sodium Carbonate (RSC): The RSC was calculated using a formula by Richards (1954)

$$\mathrm{RSC} = [(\mathrm{HCO_3^-}) - (\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}})] \tag{5}$$

Where, Ca^{2+}, Mg^{2+} and HCO_3^- are concentrations in milli-eqivalent per litre (meq/L)

IRRIGATION WATER CLASSIFICATION

United States Salinity Laboratory (USSL) Diagram

According to Richards (1954), "A graphical presentation of EC and SAR is an important parameter for determining the suitability of groundwater for irrigation purposes."The Salinity Laboratory of the United States Department of Agriculture (USSL) recommends SAR because of its direct relation to adsorption of Na^+ by soil. The different classes of salinity hazard include low, C1 (EC < 250 μS/cm); medium, C2 (EC 250–750 μS/cm); high, C3 (EC 750 -2250 μS/cm); and very high, C4 (EC > 2250 μS/cm), and the sodium hazard classes include: low, S1 (SAR < 10); medium, S2 (SAR 10 -18); high, S3 (SAR 18–26); and very high, S4 (SAR > 26).

Wilcox Diagrams

Sodium Adsorption Ratio and Soluble Sodium Percentage are widely used for assessing the suitability of water for irrigation purposes and the Wilcox diagram (Wilcox, 1995) relates a plot of SAR vs EC and SSP vs EC to designate irrigation water quality.

The different classes of the Wilcox SAR vs EC diagram include low, C1 (EC < 250 μS/cm); medium, C2 (EC 250–750 μS/cm); high, C3 (EC 750 -2250 μS/cm); and very high, C4 (EC > 2250 μS/cm), and the sodium hazard classes include: low, S1 (SAR < 10); medium, S2 (SAR 10 -18); high, S3 (SAR 18–26); and very high, S4 (SAR > 26).

The different classes of the Wilcox SSP vs EC diagram include: 'Excellent to Good', 'Good to Permissible', 'Permissible to Doubtful', 'Doubtful to Unsuitable' and 'Unsuitable'.

III. RESULTS AND DISCUSSION

Hydrogeochemistry

In this study, the cations plotted in the Piper diagram (Fig. 2) showed a dominance of the Sodium (Na^+) and Potassium (K^+) type on all the samples. In the anion plot, the chloride and bicarbonate types were predominant. 40% of the anions (stations 3 & 5 at Rumuola, station 4 at Rumuigbo and stations 1, 3 & 5 at

Rumuokwuta) were of the chloride type; 40% of the samples (station 4 at Rumuola, stations 1, 2, 3 & 5 at Rumuigbo and station 4 at Rumuokwuta) were of the bicarbonate type; 13% were of the no-dominant type (station 1 at Rumuola and station 2 at Rumuokwuta); while 7% was of the Sulphate type (station 2 at Rumuola).

The diamond plot revealed that the samples were confined to the sodium chloride, sodium bicarbonate and mixed types. The sodium chloride type dominated with 60% of the samples (stations 1, 2, 3 & 5 at Rumuola, station 4 at Rumuigbo and stations 1, 2, 3 & 5 at Rumuokwuta); 33% of the samples were of the sodium bicarbonate type (station 4 at Rumuola and stations 1, 2, 3 & 5 at Rumuigbo); while 7% of the samples were of the mixed type (station 4 at Rumuokwuta). Other faces from the diamond plot revealed that 60% of the samples show that strong acids exceed weak acids while 40% of the samples show that weak acids exceed string acids. They also reveal that in all the water samples, the alkali metals exceed the alkali earth metals; an indication that the groundwater in the study areas is soft. Water hardness is caused primarily by the presence of cations such as calcium and magnesium and anions such as carbonate, bicarbonate, chloride and sulphate in water (Sadashivaiah *et al.*, 2008).

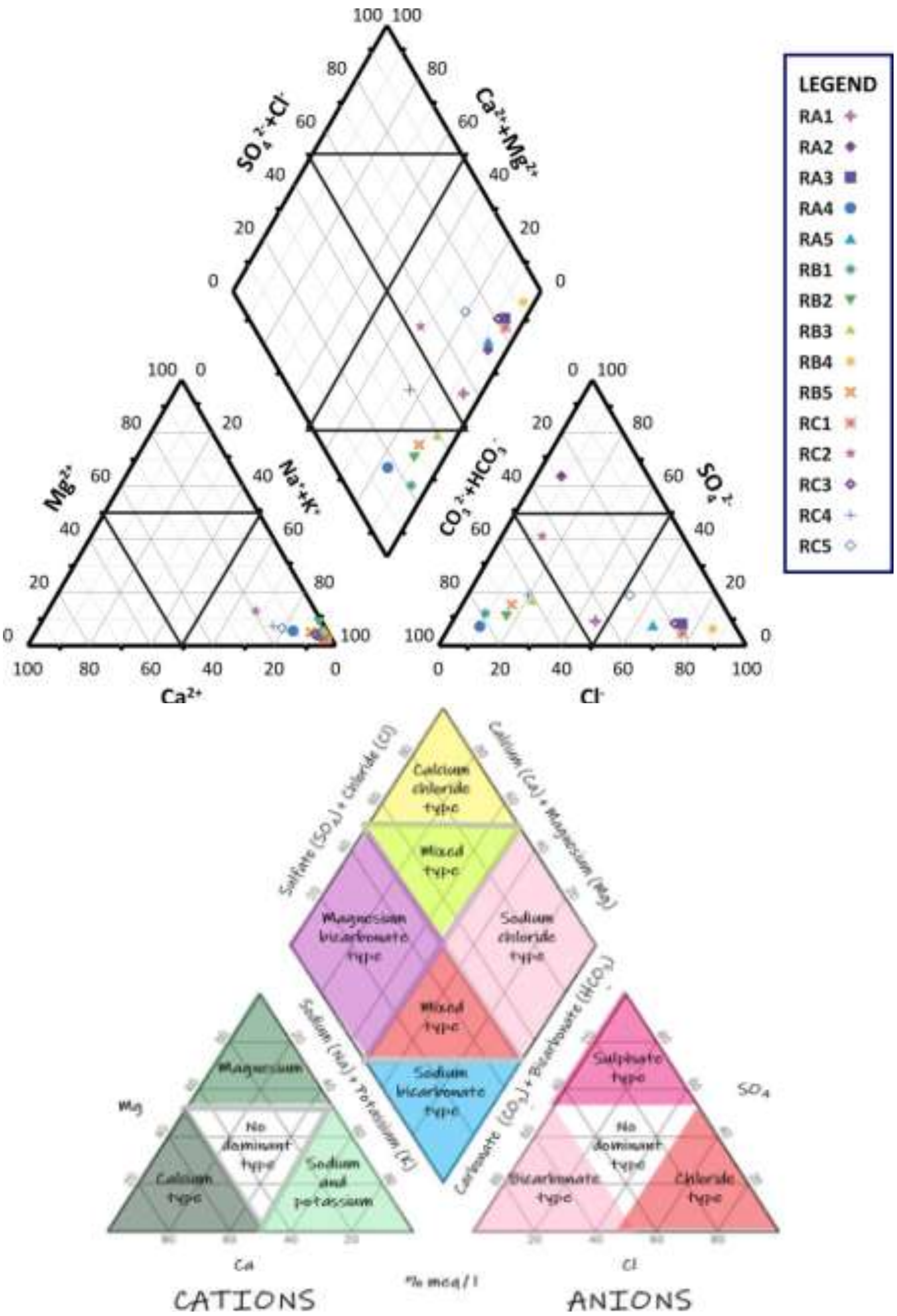

Fig 2: Piper Trilinear Diagram

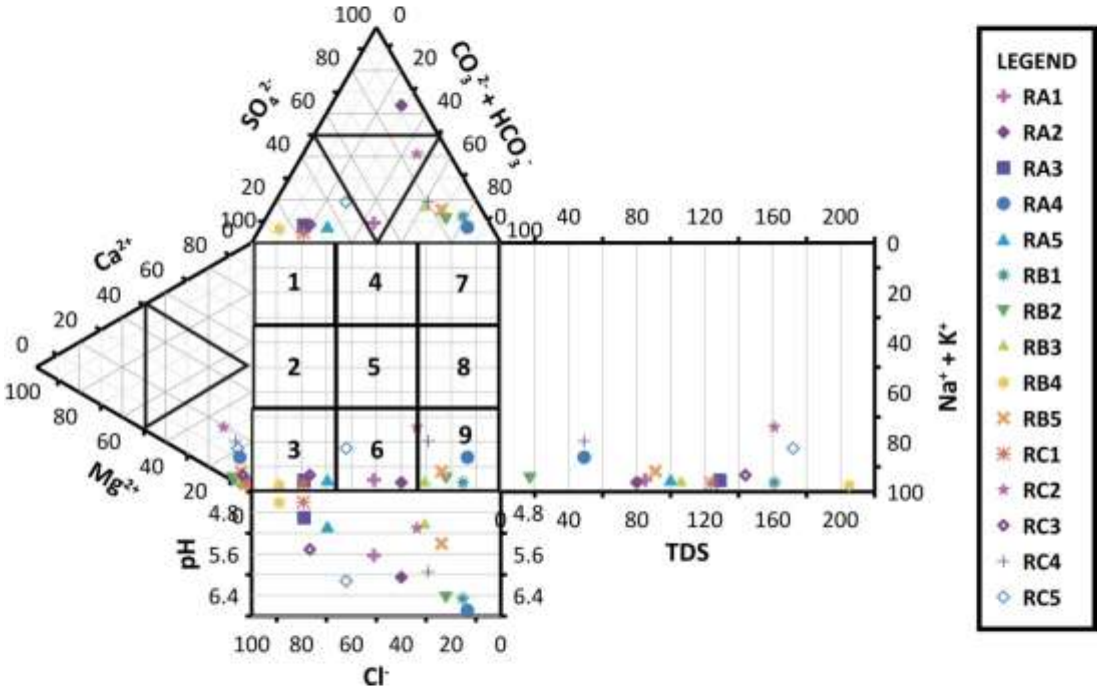

Fig. 3: Durov Diagram

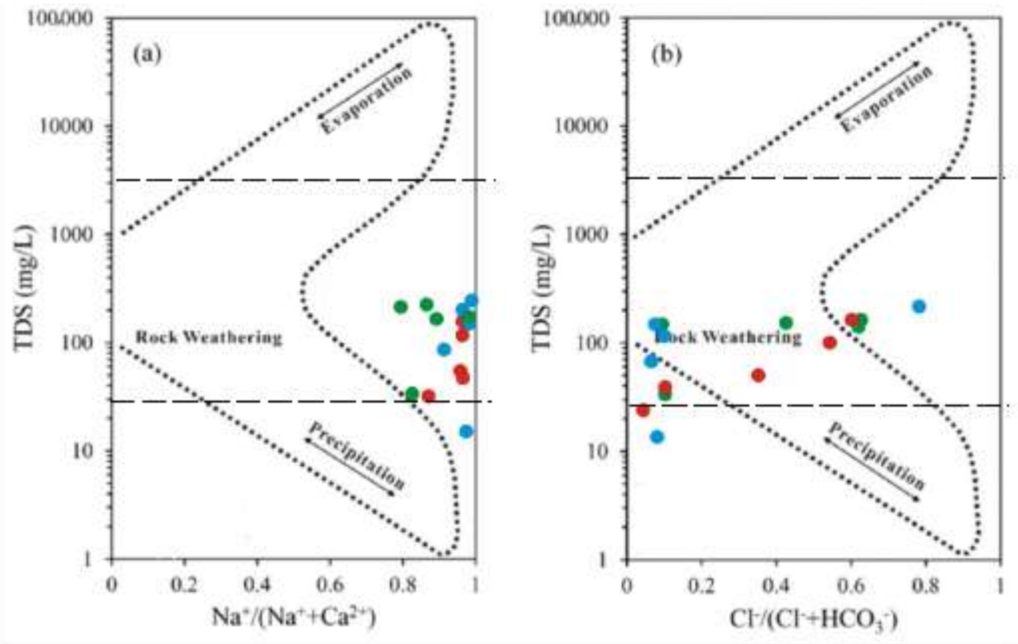

Fig. 4: Gibbs diagram

From the Durov diagram (Fig. 3) of the study area, the triangular plots for cations and anions were very similar to those obtained from the Piper diagram (Fig. 2), confirming the distribution of the ions in the water and classification of the water types.The square plots in the Durov diagram interpret the hydrogeochemical processes (Lloyd and Heathcoat, 1985). It was observed that water in the study area had 33% of water samples indicating reverse ion exchange; 27% of the water samples resulted from ion dissolution or mixing while 40% of the water samples indicated reverse ion exchange of to be the main hydrogeochemical processes affecting the groundwater quality. The rectangular plots also revealed that the water in the study area is fresh, having Total Dissolved Solids levels within 0 ppm – 1000 ppm (Carroll, 1962), and the water in the area is acidic.

The data points on the Gibbs diagram (Fig. 4) suggest that groundwater chemistry is controlled principally by rock weathering and to a lesser extent, precipitation. The 'rock-water interaction dominance' field indicates the interaction between rock chemistry and the chemistry of the percolation waters under the subsurface (Singh and Kumar, 2015). The diagram does not imply the absence of the effects of evaporation on groundwater chemistry; instead it suggests that evaporation has insignificant influence when compared to the other two processes.

Irrigation Indices

Irrigation is an agricultural practice used to mitigate the lack of adequate soil moisture resulting from insufficient rainfall (George, 2004). According to Cooper and Lipe (1992), "poor quality water may affect irrigated crops by causing accumulation of salts in the root zone, by causing loss of permeability of the soil due to excess sodium or calcium leaching, or by containing pathogens or contaminants which are directly toxic to plants or to those consuming them". Because of the direct relationship between crop yield and the quality of water used for irrigation, it's necessary to assess irrigation water in order to achieve adequate food production and poverty eradication (Shahid *et al*., 2006).

The irrigation indices used in this study include Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SPP), Kelly Ratio (KR), Permeability Index (PI) and Residual Sodium Carbonate (RSC). Ratings of the boreholes in the study area using these indices are shown in Figs. 5 – 9.

From the Sodium Adsorption Ratio (SAR) rating (Fig. 5), all the boreholes in the study area were rated as "excellent" for irrigation purposes (SAR<10). The SAR index is significant in assessing the suitability of irrigated water in relation to sodium hazard (Srinivasamoorthy *et al.*, 2014; Subramani *et al.*, 2005). The SAR value represents the sodium hazard.

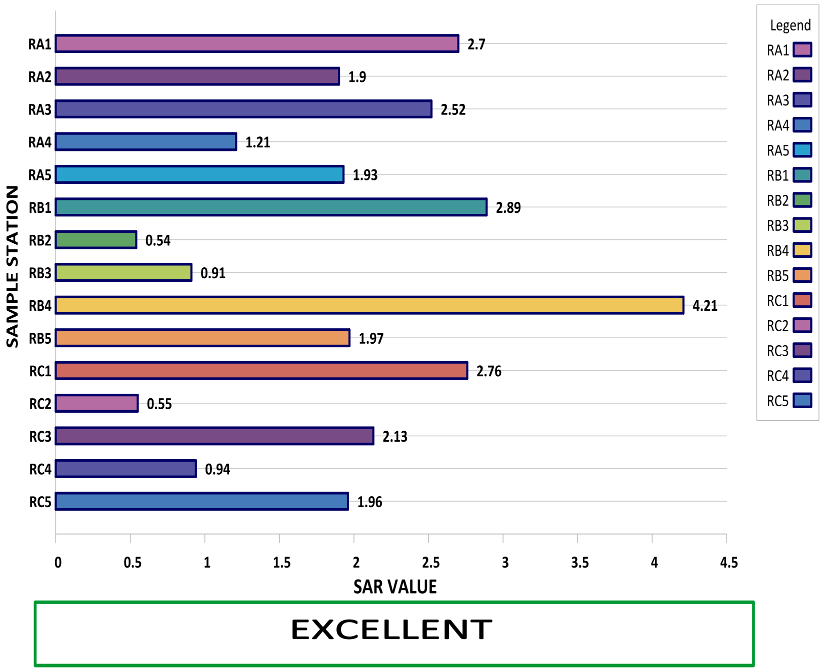

Fig. 5: Sodium Adsorption Ratio (SAR) Values

Fig. 6: Soluble Sodium Percentage (SSP) Values

Fig. 7: Kelly Ratio (KR) Values

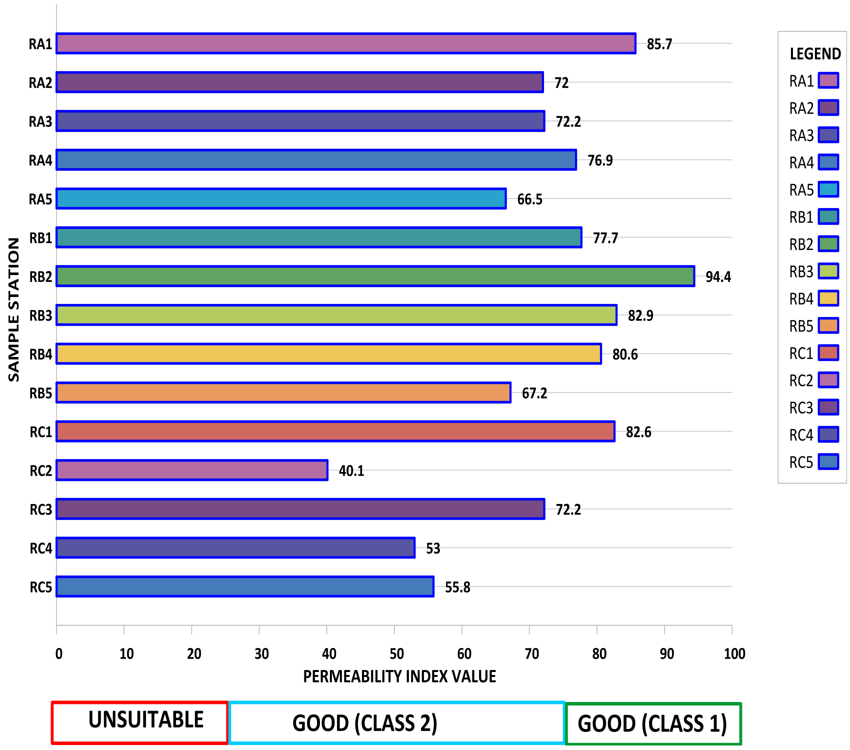

Fig. 8: Permeability Index (PI) Values

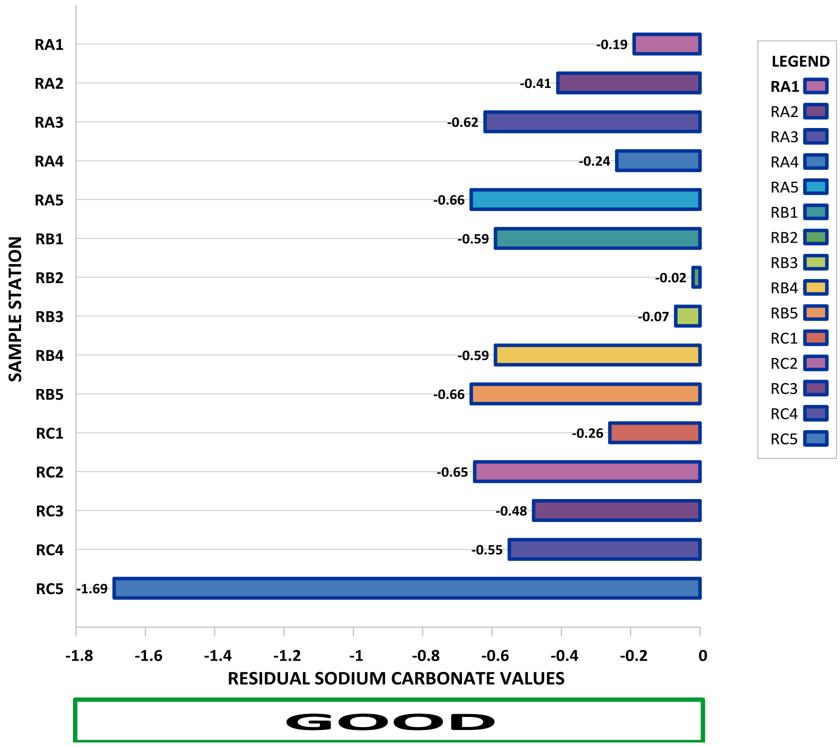

Fig. 9: Residual Sodium Carbonate (RSC) Values

The Soluble Sodium Percentage (SPP) values (Fig. 6) show that only 1% of the boreholes (station 2 at Rumuokwuta) had water rated as "good" for irrigation purposes (SPP = 31.0); 27% of the boreholes (Station 4 at Rumuola, Station 2 at Rumuigbo and Stations 4&5 at Rumuokwuta) had their water rated as "permissible" for irrigation purposes (SPP= 40-60) while 67% (Stations 1, 2, 3 & 5 at Rumuola, Stations 1, 3, 4 & 5 at Rumuigbo and Stations 1 & 3 at Rumuokwuta) were rated as "doubtful" (SPP = 60 - 80). According to Purushothman *et al.* (2012), "high contents of Na^{+} in water, relative to Ca^{2+} and Mg^{2+} concentrations, react with soil and decrease its permeability, which contributes to a deterioration of the soil structure resulting to stunted plants".

Kelly Ratio (KR) values in this study (Fig. 7) showed that 33% (Station 4 at Rumuola, Station 2 at Rumuigbo and Stations 2, 4 & 5 at Rumuokwuta)of boreholes in the study area have their water rated as "good" for irrigation purposes (KR<1) while 67% (Stations 1, 2, 3 & 5 at Rumuola, Stations 1, 3, 4 &5 at Rumuigbo and Stations 1 & 3 at Rumuokwuta) have their water rated as "doubtful" (KR>1). The KR indicates sodium concentration levels in water (Sudhakar and Narsimha, 2013). The KR values lower than one (KR < 1) are suitable for irrigation, whereas values greater than one (KR > 1) are unsuitable due to hugs sodium concentration (Sundaray, 2009).

Permeability Index (PI) values in this study (Fig. 8) showed that 47% (Stations 1& 4 at Rumuola, Stations 1, 2, 3 & 4 at Rumuigbo and Station 1 at Rumuokwuta)had their water rated as "Good (Class 1)" while 53% (Stations 2, 3 & 5 at Rumuola, Station 5 at Rumuigbo and Stations 2, 3, 4 & 5 at Rumuokwuta) had their water rated as "Good (Class 2)".The PI assesses the suitability of irrigation water, which is influenced by high concentrations of Na^{+}, Ca^{2+}, Mg^{2+} and alkalinity ions (Ravikumar *et al.*, 2011).

Residual Sodium Carbonate (RSC) values (fig. 9) show that all the boreholes in the study area had their water rated as "good" for irrigation purposes (RSC < 1.25). The alkalinity content is important in determining the suitability irrigation water and its concentration in excess of alkaline earth metals, which indicates the hazardous effect of alkalinity irrigation water, is termed 'Residual Sodium Carbonate' (Sundaray, 2009; Ravikumar *et al.*, 2011).

Classification of Irrigation Water

The USSL diagram (Fig. 10) indicated that 93% of the samples fell in the C1-S1 group indicating Very Good water quality; having low salinity and low sodium. Station 4 at Rumuigbo had its water plotted in the C2-S1 group indicating Good water quality, having medium salinity and low sodium. C1-S1 classes are perfect for irrigation. C2-S1 classes can be used for irrigation on almost all soils with little danger of sodium problem. C4-S4 classes are generally not suitable for irrigation. C2-S4, C3-S2 and C3-S4 classes are marginal /doubtful for irrigation.

These results were also confirmed in the Wilcox (SAR vs Conductivity) diagram as shown in Fig. 11.The Wilcox (Sodium Percent Vs Electrical Conductivity) diagram (Fig. 12) also showed that all the water samples in the study area fell into the Excellent to Good water class; suitable for irrigation purposes. This is in agreement with the USSL classification.

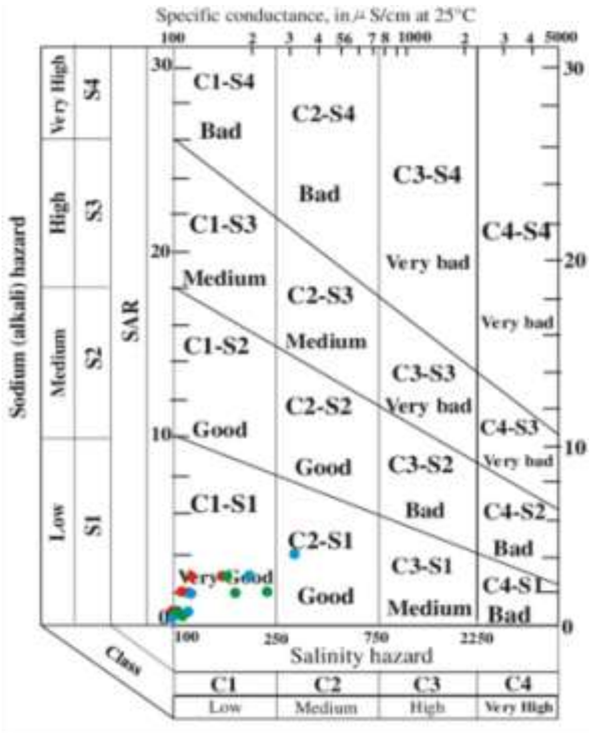

Fig. 10: United States Salinity Laboratory (USSL) Diagram for Classification of Water in the Study Areas for Irrigation

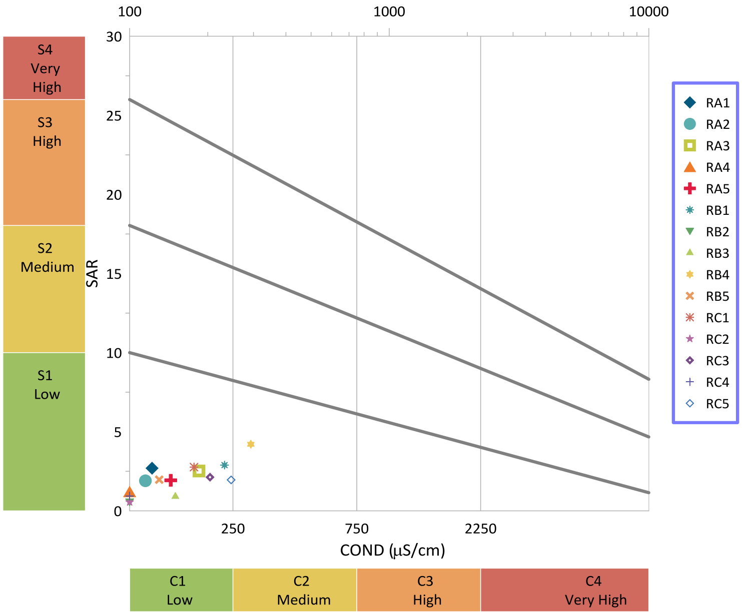

Fig. 11: Wilcox (SAR vs Conductivity) Diagram for Classification of Water in the Study Area for Irrigation Suitability

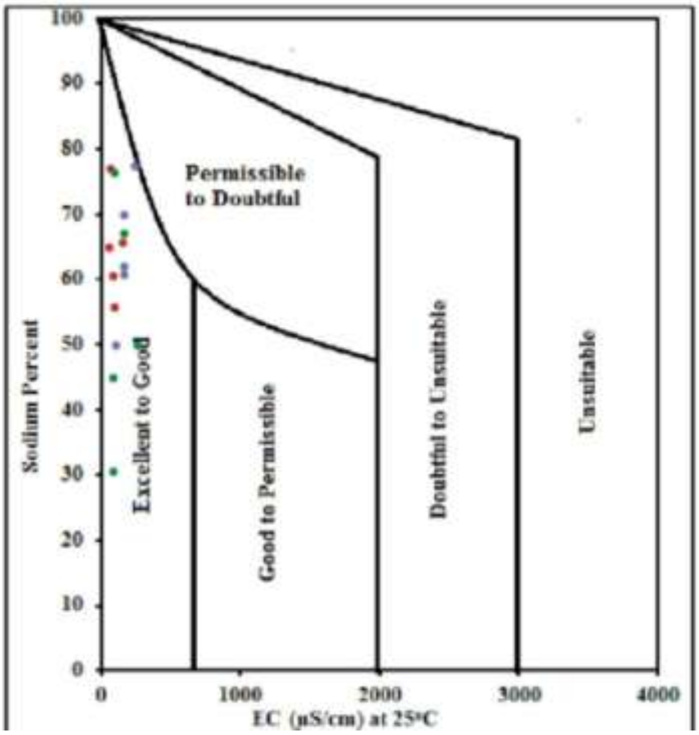

Fig. 12: Wilcox (Sodium Percent vs Conductivity) Diagram for Classification of Water in the Study Area for Irrigation Suitability

IV. CONCLUSION

Assessmentof groundwater in the study area has shown that water in the area is acidic, fresh and having temporary hardness.EC, TDS, HCO_3^-, alkalinity and salinity levels were all within acceptable limits.

The piper diagram reveal that Na^+, HCO_3^- and Cl^- were the dominant cations and ions while water in the area fell predominantly into the sodium chloride and sodium bicarbonate type.

The Durov diagram indicated that ion-exchange, reverse ion-exchange and simple dissolution processes control groundwater quality in the area while Gibbs diagram further revealed that rock weathering process also plays a role in controlling groundwater quality.

Determination of irrigation indices show that SAR rated water in the area as ‘excellent’, SSP and KR rated most of the water as ‘doubtful’, while PI and RSC rated as ‘good’ for irrigation purposes.

Plots of the USSL and Wilcox diagrams classified water in the area as ‘excellent’ for irrigation purposes. Thus, it can be established from this study that groundwater in the area is suitable for irrigation purposes; it can support plant growth and promote efficient yield without posing problems of salinity or permeability hazard to the soil.

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