FUPRE Journal of Scientific and Industrial Research
Vol.2, (1), 2018
ISSN: 2579-184 (Print) ISSN: 2578-1129 (Online)

Integration of Hydrogeochemical Analytical Methods and Irrigation Parameters in the Evaluation of Groundwater Quality at Ibinta, Southern Benue Trough Nigeria

O. O. Omo-Irabor[1*], M. O. Eyankware[2],C. Ogwah[2]
[1]Department of Earth Sciences, Federal University of Petroleum Resources. Effurun, Nigeria
[2]Department of Geology, Faculty of Science Ebonyi State University, Abakaliki. Nigeria

*Email: omoirabor.omoleomo@fupre.edu.ng

Abstract

Groundwater quality assessment for irrigation purposes was carried out using America Public Health Association standard method for the following parameters: pH, turbidity, electrical conductivity (EC), total dissolved solids (TDS), Mg^{2+}, Ca^{2+},Cl^- and SO_4^{2-}. Hydrogeochemical facies analysis from Piper plot and Durovindicate the dominance of SO_4^{2-}+ Mg^{2+}water type.Irrigation parameters analyzed showed that electrical conductivity was in the range of 58.14 to 965.87µS/cm, soluble sodium percentage (SSP) ranged between 2.04 to 26.66, sodium percentage (Na%) varied from 2.08 to 30.23 %,Kelly ratio (KR) ranged from 0.003 to 0.3 and total hardness (TH) was between 11.00 to 67.50in the study area. The above estimated parameters satisfy the various permissible standard values for irrigation.However, SSP and SAR are slightly above various permissible standard values for irrigation.It was observed that SSP, Na%, KR and TH were considered fit for irrigation.

Keywords: Groundwater quality, Hydrogeochemical facies, Irrigation parameters

1.0 Introduction

Water is a necessity for all living organisms, moreso plants require quality water for proper functioning. It exists as surface water and groundwaterand groundwater is considered relatively free from pollution compared to surface water (Rilwanu, 2013). Water required for irrigation purposes need to be of acceptable standard and this varies depending on the composition of the sediment that hosts the water and the travel path through which groundwater infiltrates and recharges the aquifer (Eyankware, et al., 2016b). Its quality varies due to prolonged stay in host medium that serves as aquifer and the longer the stay the larger the rock water interaction. Background geochemistry is an important tool for evaluating the hydrochemistry of water and for the monitoring of water quality. Cocker (1995); Pazand, *et al*., (2011)stated that hydrochemistry of groundwater is principally controlled by the rocks and sediments through which these waters flow through. However, the occurrence of groundwater depends on the development of secondary porosity and permeability by weathering and/or fracturing of the parent rocks especially within the Asu River Group (Eyankware, *et al*., 2018). Groundwater is exploited from existing fractured shale and limestone within the study area (Agumanu, 1989;Nwajide, 2013). Generally, the movement and storage of groundwater within the area is controlled by three major factors namely; lithology thickness and structure of rock formation (predominantly shales of the Asu River Group). Shale is an aquiclude and does not permit accumulation of reasonable quantity of water, especially when fresh and unweathered, but considerably aquiferous when fractured, the same implies to limestone. The study is therefore carried out to ascertain the influence of lithology on the groundwater chemistry and to consequently suggest whether or not the water is suitable for irrigation purposes.

1.1 Location of Study Area and Geology

The study area is located in Iyahe local government area of CrossRiver state. Geographically the study covers between latitudes $6^0 30'$N - $6^0 40'$N and longitudes $8^0 20'$ E - $8^0 30'$ E. The area is accessible by Abakaliki/Ogojaroad, with some other minor roads (Fig.1). The stratigraphy of the southern Benue Trough wasdescribed by Murat (1972) and Hoque (1977) using theconcept of three tectonic sedimentary cycles. Three suchcycles of marine transgressions and regressionsoccurred from the Albian to the Coniacian (Nwajide,2013). The first marine transgression of the BenueTrough occurred in the Middle Albian period, with the deposition of the Asu River Group in the Southern BenueTrough (Murat, 1972). Reyment, (1965), described the Asu River Group sediments as predominantly shales, siltstone, sandstone and limestone facies aswell as extrusive and intrusive rocks. The Asu River Grouphas an average thickness of about 2000m anduncomfortably overlies the Precambrian Basement(Benkhelil, *et al.*, 1989). The Santonian tectonic phaseresulted in series of fracturing and folding of these rocks, giving rise to chains of anticlines and syncline known as the Abakaliki Anticlinorium (Reyment, 1965). The majorfracture system which hosts the lead-zinc mineralization runs in the NW- SE and NNW-SSEdirections as shown in (Fig. 2).Oha, *et al.*, (2017), explained that there is the presence of barium and also lead zinc mineralsthat exist in veins, and the minerals areinterwoven with the igneous bodies. The igneous intrusives located a few meters away from the study area, have widthsof between 5cm – 200cm and lengths of between 2m – 30m. In2010, artisanal exploiters abandoned the mining of the minerals as a result ofthe intricate associationof the veins and the igneous bodies, which posedgreat difficulty for miners to extract the ore.

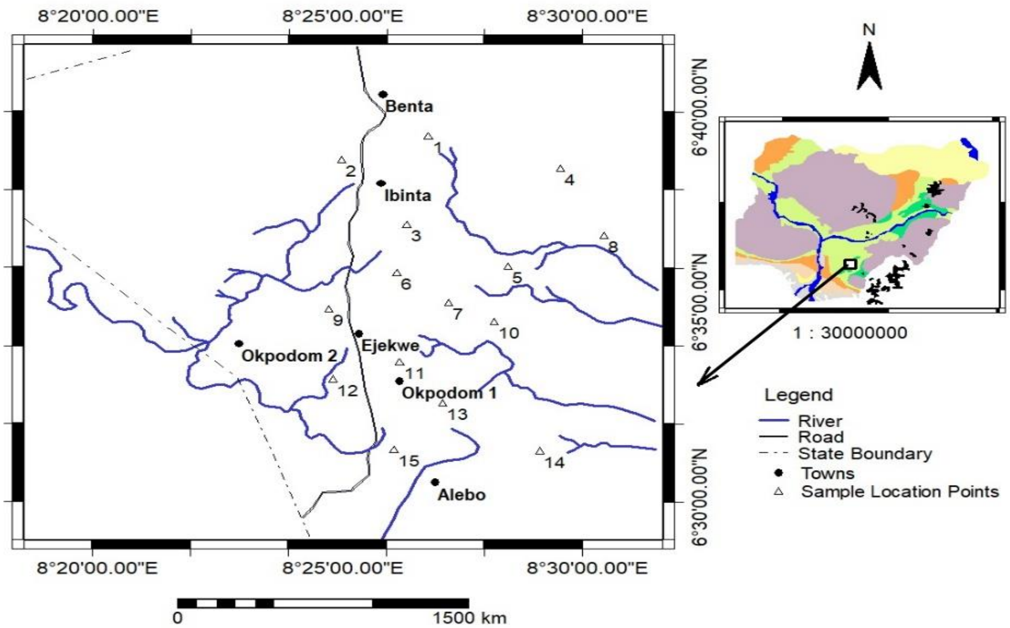

Figure 1: Sample location map

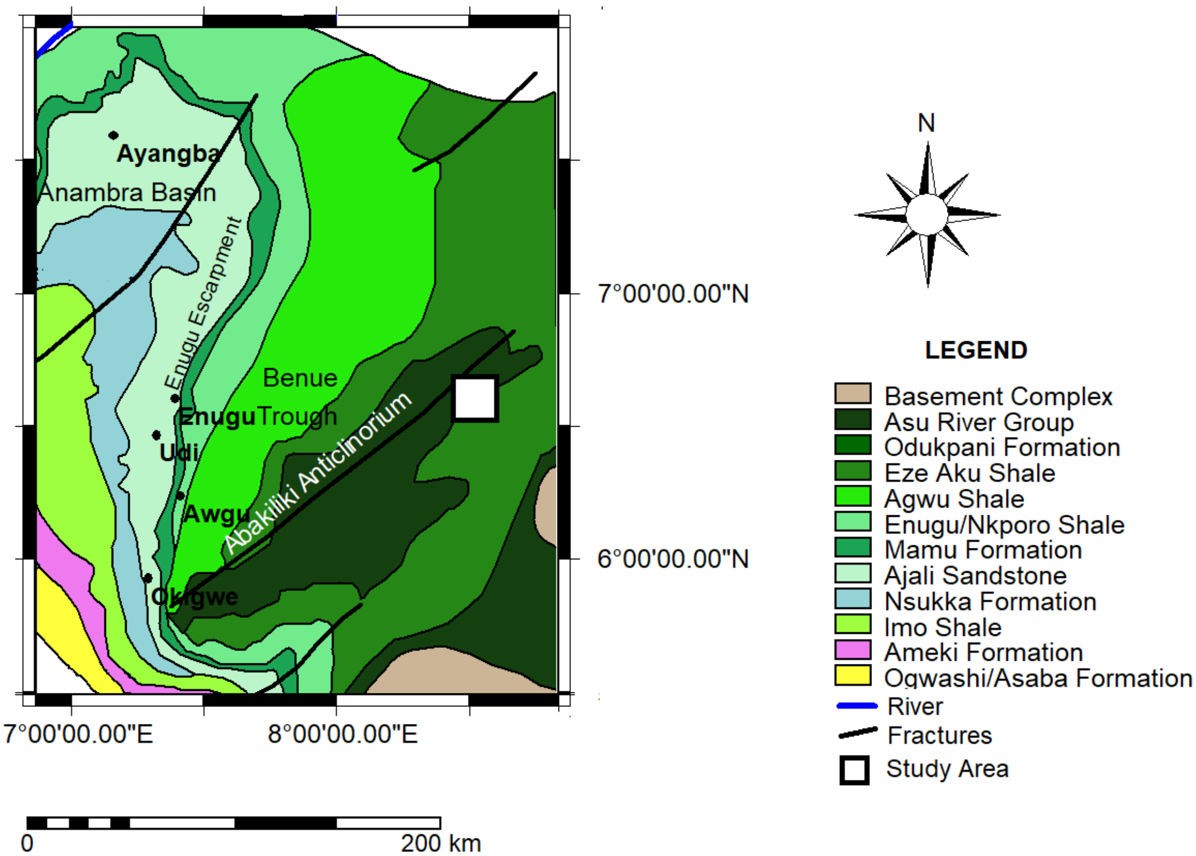

Figure 2: Geological map of the study area showing major fracture systems

2.0 Materials and Methods

Fifteen water samples were collected from boreholes at different points and analyzed for their physicochemical properties (Fig.1). Precautionary measures were taken by washing the bottles with clean water and cleaning reagents and thoroughly rinsing with distilled, de-ionized water prior to collection of water sample from site. Electrical Conductivity (EC), pH and Total Dissolved Solids (TDS) were determined at points of collection, samples were sealed and stored in ice chests and eventually transported to the laboratory within an hour of the collection.Electrical Conductivity and Total Dissolved Solids were determined using the HACH Conductivity and TDS meters respectively. The pH was measured using a pH meter. Potassium (K) and Sodium (Na) ion concentrations were obtained with a Jenway clinical flame photometer. Calcium (Ca), magnesium (Mg), and chloride (Cl) ions were determined using appropriate titrimetric methods described by APHA (2012), and the sulphate concentration was determined by turbidimetry. The accuracy of geochemical analysis was determined by calculating the ion balance, which was within ±5 %. Irrigation parameters were determined by calculation using the relations below in (meq/L).

The **Soluble Sodium Percentage (SSP)** is an irrigation parameter used for the assessment of the quality of water and can becalculated using the equation as proposed by Todd (1980)

$$SSP = \frac{Na^{+} \times 100}{Ca^{2} + Mg^{2} + Na^{+}} \quad (1)$$

According toLaze, *et al.*, (2016), magnesium content is considered as one of the most important criteria for irrigation water assessment and most waters maintain equilibrium status between Ca and Mg. The **Magnesium Adsorption Ratio (MAR)** was calculated using equation 2(Raghunath, 1987).

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

Sodium Percentage (Na%)is an important parameter for classifying irrigation water as the permeability of the soil is reduced by it reacts with sodium and is computed using the formula(Eaton 1950;Doneen, 1964).

$$Na\% = \frac{Na^{+} \times 100}{Ca^{2+} + Mg^{2+}} \quad (3)$$

Sodium Adsorption Ratio (SAR) is the extent to which sodium can be absorbed by soil. This was calculated from the equation proposed by Richards, (1969).

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (4)$$

The alkali hazard of the major cations is determined by **Kelly's Ratio (KR)** (Kelly 1963). It is used to determine the suitability of the quality of water for agricultural purpose.

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad (5)$$

Total Hardness (TH) (Sawyer and McCarty, 1967;Raghunath, 1987).

$$TH = (Ca^{2+} + Mg^{2+}) \times 100 \quad (6)$$

Permeability Index (PI) (Doneen, 1964).Soil permeability is affected by both high sodium and carbonate/bicarbonate content in water, the PI index can thus be used to calculate the effect on permeability.

$$PI = \frac{Na^{+}\sqrt{HCO_3^{-}}}{Ca^{+} + Mg^{2+} + Na^{+}} \quad (7)$$

Gibb's Plot

For Cations

$$Na^{+}/(Na^{+} + Ca^{2+}) \ meq/L \quad (8a)$$

For Anions

$$Cl^{-} + HCO_3^{-}) \text{ meq/L} \quad (8b)$$

3.0 Results and Discussion

3.1 Physicochemical Parameters (pH, EC, TDS)

The result for the physicochemical parameters presented in Table 1 was used to assess the water for its usability for domestic and irrigation Purposes with the ionic concentrationsin the order; Mg^{2+}>Ca^{2+}> Na^{+}.

pH

From the Table 1, the measured pH is found to be slightly acidic to basic and ranges from 6.1 to 7.2.

These values fall within the World Health Organization (WHO) permissible range of 6.00 to 8.50 for drinking water and irrigation purposes. Various factors are responsible for change in pH value.These include: interaction with surrounding rocks, particularly carbonate rock, acid rainand waste from mining.Groundwater pH varies depending on the composition of the sediments that surround the travel pathway of the recharge water infiltrating tothe groundwater andalso due to prolong stay in particular rock that serves as aquifer which host the water. The longer the stay, the larger the rock water interaction.

Table 1. Results of physicochemical parametersof water samples

Sample Code	EC (µS/cm)	TDS (mg L^{-1})	pH	Mg^{2+} (meq/L)	Na^{+} (meq/L)	Ca^{2+} (meq/L)	SO_4^{2-} (meq/L)	Cl^{-} (meq/L)	CO_3^{2-} (meq/L)	HCO_3^{-} (meq/L)
IBT/01	377.49	189.57	6.3	0.34	0.13	0.09	2.48	1.01	0.52	0.87
IBT/02	584.33	295.03	6.4	0.71	0.08	0.13	1.32	0.36	0.38	0.63
IBT/03	295.08	116.43	6.1	0.83	0.02	0.06	2.51	0.22	0.64	0.91
IBT/04	503.58	346.06	6.5	0.92	0.04	0.15	3.85	1.38	0.15	0.37
IBT/05	89.23	73.59	7.2	1.33	0.05	0.02	1.97	0.31	0.76	1.22
IBT/06	604.92	436.86	6.4	0.46	0.02	0.08	3.39	0.83	0.03	0.30
IBT/07	279.30	171.54	6.3	0.65	0.06	0.05	2.12	1.99	0.27	0.81
IBT/08	491.28	293.76	6.8	0.19	0.01	0.03	1.93	0.18	0.14	0.37
IBT/09	58.14	190.54	7.0	0.27	0.03	0.09	3.22	0.33	0.25	0.54
IBT/10	700.38	407.11	6.9	0.51	0.04	0.12	2.94	0.51	0.91	1.49
IBT/11	529.10	285.05	6.4	0.83	0.07	0.01	3.61	0.32	0.21	0.36
IBT/12	909.38	553.19	6.2	0.72	0.15	0.03	2.85	0.72	0.38	0.84
IBT/13	711.45	385.96	6.4	0.16	0.03	0.06	3.06	0.46	0,41	0.93
IBT/14	965.87	491.38	6.5	0.52	0.06	0.02	2.17	0.58	0.85	1.19
IBT/15	180.62	73.05	6.3	0.82	0.02	0.13	3.42	1.02	0.06	0.36
Mean	**485.34**	**287.27**	**6.5**	**0.62**	**0.05**	**0.07**	**2.72**	**0.68**	**0.40**	**0.75**
Minimum	**58.14**	**73.05**	**6.1**	**0.16**	**0.01**	**0.01**	**1.32**	**0.18**	**0.03**	**0.30**
Maximum	**965.87**	**553.19**	**7.2**	**1.33**	**0.15**	**0.15**	**3.85**	**1.99**	**0.91**	**1.49**
Standard deviation	**274.77**	**150.11**	**0.3**	**0.31**	**0.04**	**0.05**	**0.72**	**0.50**	**0.29**	**0.37**

Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

Electrical conductivity values of the water samples ranged from 58.14 to 965.87µS/cm (Table 1). This parameter is related to the concentration of salts dissolved in water salinity (Fig.3).This implies that areas with high electrical conductivity values correspond to areas that have high concentrations of total dissolved solid. TDS values for water sample from area ranged from 73.05 – 553. 19 mg/L (Table 1). The higher the values of EC, the smaller the amount of water available for use by plants. (Joshi, *et al*, 2009).

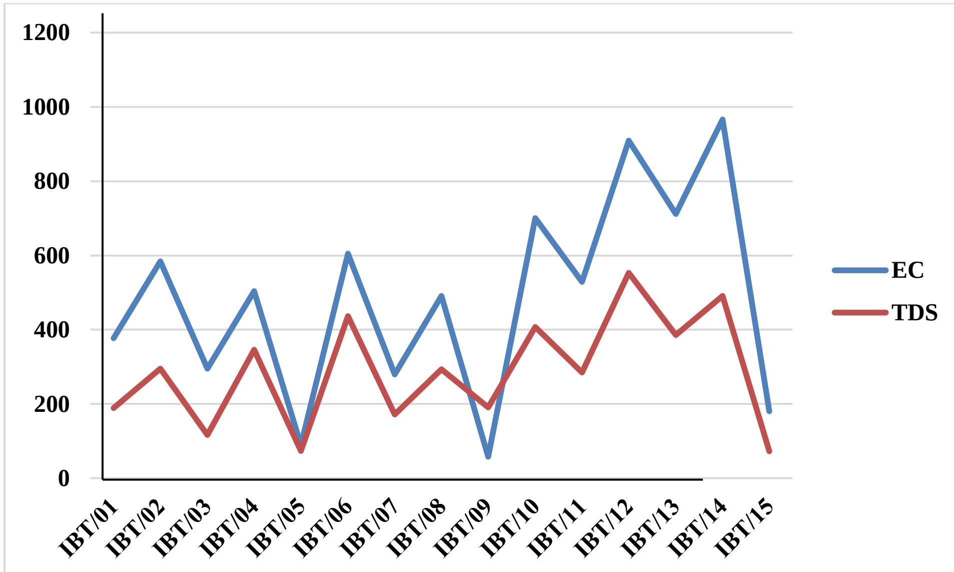

Figure 3: Plot of Electrical Conductivity against TDS

Based on Richards (1969) classification scheme, it can be observed from Table 2, samples IBT/05, 09 and 15 fell into the category of excellent while none of the samples was unsuitable for irrigation purposes.

Table 2: Classification of water based on EC (Richards, 1969)

Salinity Hazard (Cla	EC µS/c	Sampling Points
Excellent(C1)	<250	IBT/05, 09 and 15
Good (C2)	250 -750	IBT/01, 02, 03, 04, 05, 07, 08, 10, 11 and 13
Doubtful(C3)	750 -2250	IBT/12 and 14
Unsuitable(C4)	>2,250	

3.2 Irrigation Parameters

The results of the calculated irrigation parameters are displayed in Table 3.

Table 3: Results of irrigation parameters

Sample Code	SSP	MAR	Na%	SAR	KR	TH	PI	RSC	RSBC	RSC/RSBC	Gibbb's Cations	Anions
IBT/01	23.21	79.06	30.23	0.61	0.30	21.5	0.22	0.96	0.78	1.23	0.59	0.34
IBT/02	21.05	2.36	26.66	5.33	0.26	42.0	0.13	0.17	0.50	0.34	0.38	0.36
IBT/03	2.19	93.25	2.24	0.18	0.08	44.5	0.20	0.66	0.85	0.78	0.25	0.19

Sample Code	SSP	MAR	Na%	SAR	KR	TH	PI	RSC	RSBC	RSC/RSBC	Gibbb's Cations	Anions
IBT/04	3.60	85.98	3.73	0.07	0.03	55.0	0.02	-0.55	0.22	-2.50	0.21	0.81
IBT/05	3.57	98.51	3.70	0.07	0.03	67.5	0.05	0.63	1.20	0.53	0.71	0.20
IBT/06	3.57	85.18	3.70	0.07	0.03	27.0	0.17	-0.21	0.22	-0.95	0.20	0.73
IBT/07	7.89	92.85	8.57	0.17	0.08	35.0	0.07	0.38	0.76	0.50	0.54	0.71
IBT/08	4.34	86.36	4.54	0.09	0.04	11.0	0.02	0.29	0.34	0.85	0.25	0.32
IBT/09	7.69	75.00	8.33	0.16	0.08	18.0	0.05	0.43	0.45	0.96	0.25	0.37
IBT/10	5.97	80.95	6.34	0.12	0.06	31.5	0.10	1.77	1.37	1.29	0.25	0.25
IBT/11	7.69	98.80	8.33	0.07	0.03	42.0	0.04	-0.27	0.35	-0.77	0.83	0.47
IBT/12	16.66	96.00	20.00	0.40	0.20	37.5	0.15	0.47	0.81	0.58	0.33	0.46
IBT/13	12.00	72.72	13.63	0.23	0.11	11.0	0.11	1.12	0.87	1.29	0.75	0.33
IBT/14	10.00	96.27	11.11	0.07	0.11	27.0	0.10	1.50	1.17	1.28	0.15	0.49
IBT/15	2.04	54.16	2.08	0.04	0.20	48.0	0.01	-0.53	0.23	-2.30	0.87	0.73
Mean	**8.76**	**79.83**	**10.21**	**0.51**	**0.11**	**34.57**	**0.10**	**0.45**	**0.67**	**0.21**	**0.44**	**0.45**
Minimum	**2.04**	**2.36**	**2.08**	**0.04**	**0.03**	**11.00**	**0.01**	**-0.55**	**0.22**	**-2.50**	**0.15**	**0.19**
Maximum	**23.21**	**98.80**	**30.23**	**5.33**	**0.30**	**67.50**	**0.22**	**1.77**	**1.37**	**1.29**	**0.87**	**0.81**
Standard deviation	**6.73**	**24.55**	**8.84**	**1.34**	**0.09**	**15.99**	**0.07**	**0.38**	**0.38**	**1.26**	**0.25**	**0.20**

SSP (Soluble Sodium Percentage)

SSP value less than 50 indicates good quality of water fit for irrigation, while values above 50 indicate that the quality of water is not suitable for irrigation (USDA, 1954). SSP value ranged from 2.04 to 23.21, based on the value obtained from SSP the sample water is considered fit for irrigation(Table 3). Fig. 4explains the suitability of the water for irrigation purposes with 87% of the water analyzed plotting in the excellent to good region of the Wilcox diagram. Only samples from IBT/12 and IBT/14 plotted in the good to permissible region of the Wilcox diagram.

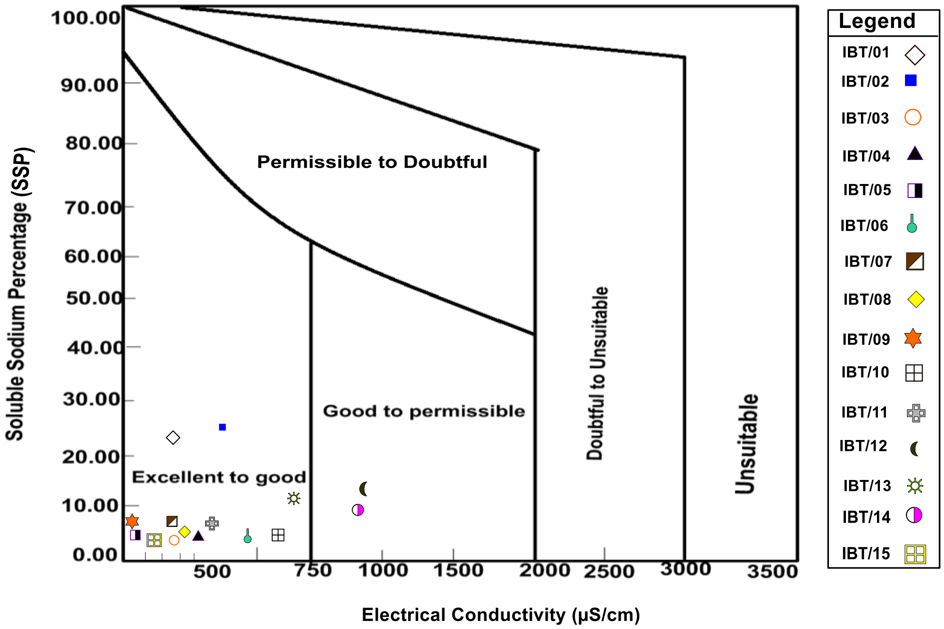

Figure 4: Wilcox diagram for groundwater in the study area

Sodium Percentage(Na%).

Na% is considered as an important factor in defining the type of irrigation. Sodium percent isanother important factor to study sodium hazard. Na% value within the study area ranged from 2.08 to 30.23 (Table 3). Fig.5., shows that sample locations fell within the good to excellent category, hence it can be deduced that the interaction between aquifer (fractured shale and limestone) host rock and groundwater has no adverse effect on groundwater quality based on sodium percentage value obtained from the study area.

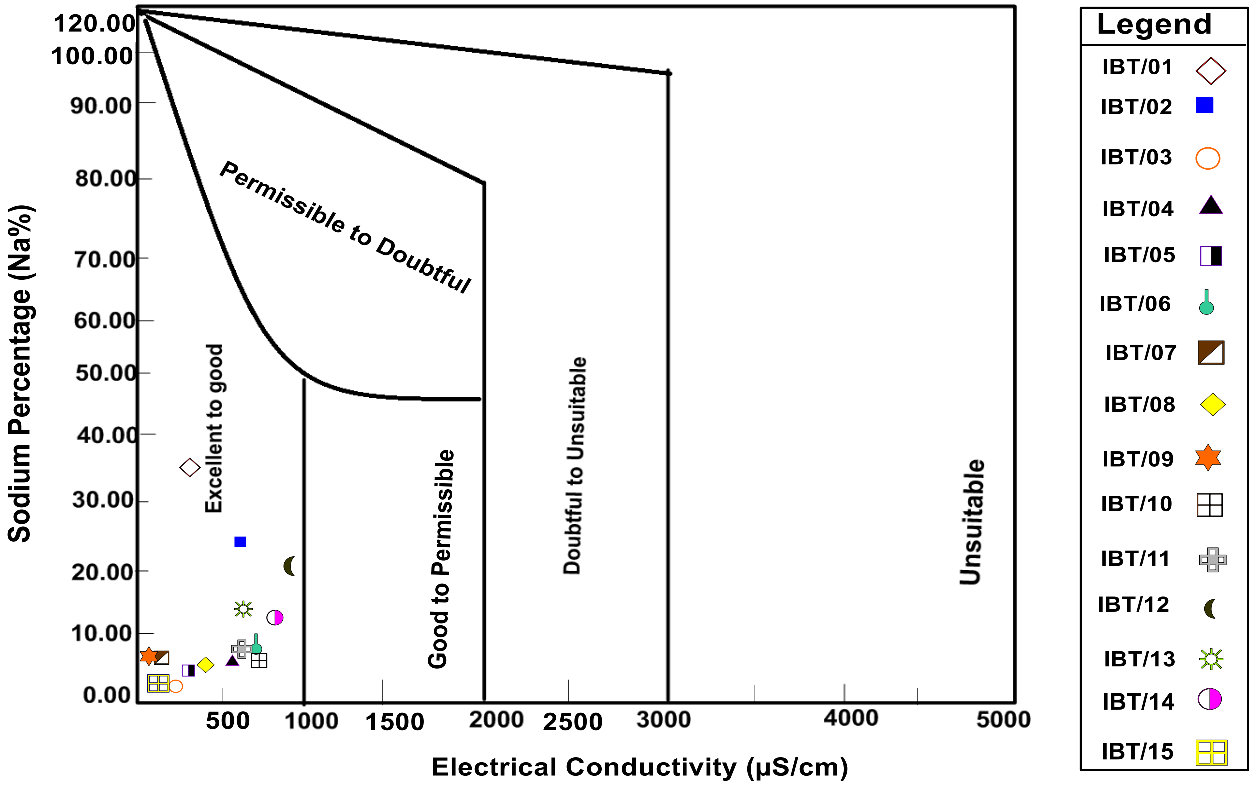

Figure 5: Rating of groundwater samples on the basis of electrical conductivity and sodium percent (after Wilcox,1955)

Sodium Absorption Ratio (SAR)

Talabi, *et al.*, (2014) stated that sodium absorption ratio is an easily measured property that gives information on the comparative concentrations of Na^+, Ca^{2+}, and Mg^{2+} in the sampled water.**SAR** takes intoconsideration the fact that the adverse effect of sodium is moderated by the presence ofcalcium and magnesium ions (Eyankware, *et al.*, 2017; 2018).Munshower, (1994); Brady, (2002) stated that SAR value above 12 to 15, poses physical soil problems and plants have difficultyabsorbing water Value of SAR ranges from 0.04 to 5.33 (Table 3). Fig.6. shows that sample locations IBT/03, 05, 07, 09 and 15 fell within excellent category based on this, these sampled locations are considered fit for irrigation. Lastly, sampled locations IBT/ 01, 02, 04, 06, 08, 10, 11 and 13 are within the C2 category hence these sample locationsare considered fit for irrigation, lastly sampled locations IBT/ 12 and 14 fell within doubtful category and are considered not fit for irrigation.

Kelly Ratio (KR)

Karanth, (1987) stated that KR of equal to or less than 1 is indicative of good quality water for irrigation whereas above 1 is suggestive of unsuitability for agricultural purpose due to alkali hazards. KR value ranges from 0.03 to 0.3 (Table 1), based on the value obtained from calculated KR, the water samplesare considered fit for irrigation.

Total Hardness (TH)

Total hardness within the study ranged from 11.00 to 67.50 (Table 3). From Table 4 it was observed that values are below >75. Hence the sampled location fell within the soft category.

Table 4: Classification of Water Based on Total Hardness (Sawyer, *et al*., 1967)

Total hardness as $CaCO_3$(mg/l)	Water Class	Number of Samples
<75	Soft	IBT/ 01 to 15
75 – 150	Moderately Hard	
150 – 300	Hard	-
`>300	Very Hard	-

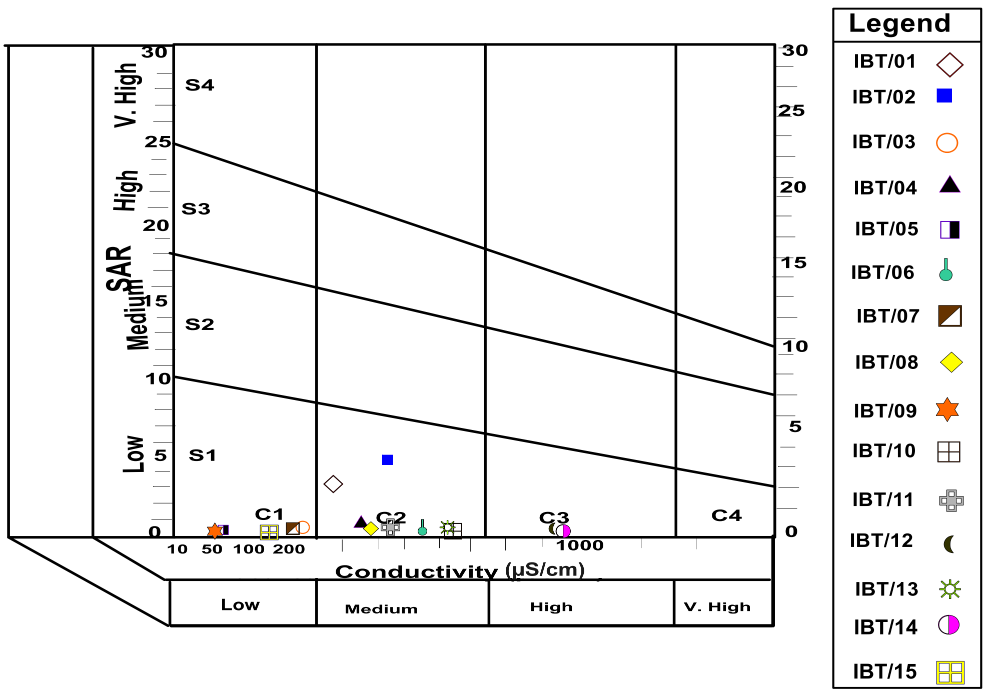

Figure 6: Classification of Groundwater based on US salinity diagram.
Where C1 = Excellent, C2 = Good, C3 =Doubtful, C4 = Unsuitable, S1 = Excellent, S2 = Good, S3=Doubtful, S4 = Unsuitable.

Permeability Index (PI)
Permeability index is classified into various category class I(>75% permeability), class II (25-75% permeability) and class III (<75% permeability) orders, with values ranging from 0.01 at sample location IBT/15 to 0.22 at sample location IBT/01. Fig. 7. Shows that sample locations IBT/04, 06, 10, 11, 12 and 15 fell within the class I category, hence the listed sample locations are considered fit for irrigation, while sample locations IBT/01, 02, 03, 05, 07, 08, 09, 13, and 14 are also considered fit for irrigation, but not as class I.

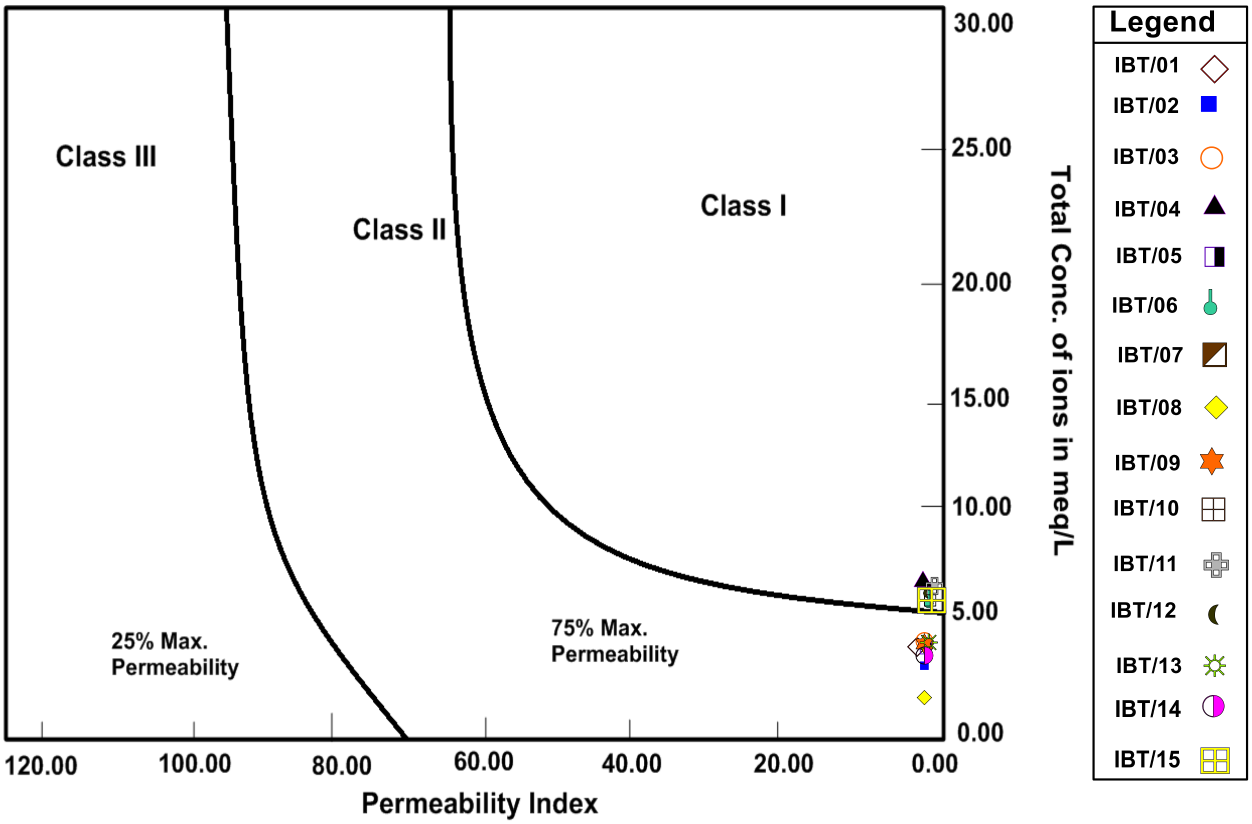

Figure 7: Doneen's, (1964) Chart for P.I. values ofwater samples

3.3 Hydrogeochemical Facies

Gibb's Plot

The concentration of dissolved ions in groundwater samples are generally governed bylithology, nature of geochemical reactions and solubility of interacting rocks (Eyankware, *et al*., 2016a).Functional sources of dissolved ions can be broadly assessed by plotting the samples, according to thevariation in the ratio of $Na^+/(Na^++Ca^{2+})$ and $Cl^-/(Cl^-+HCO_3^-)$ as a function of TDS(Gibb's, 1970). Gibb's plot is usually used to determine the major factor controlling groundwater interaction. Fig. 8. It was observed that for cations, samples IBT/01, 02, 03, 04, 06, 07, 08, 09, 10, 11, 12, 13 and 14 groundwater chemistry is being controlled by rock dominance except for samples IBT/05 and 15 where groundwater is controlled by precipitation dominance, while for anions sample locations IBT/01 to 15 groundwater chemistry is controlled by rock water interaction except for sample location IBT/10 where groundwater chemistry is controlled by precipitation dominance.

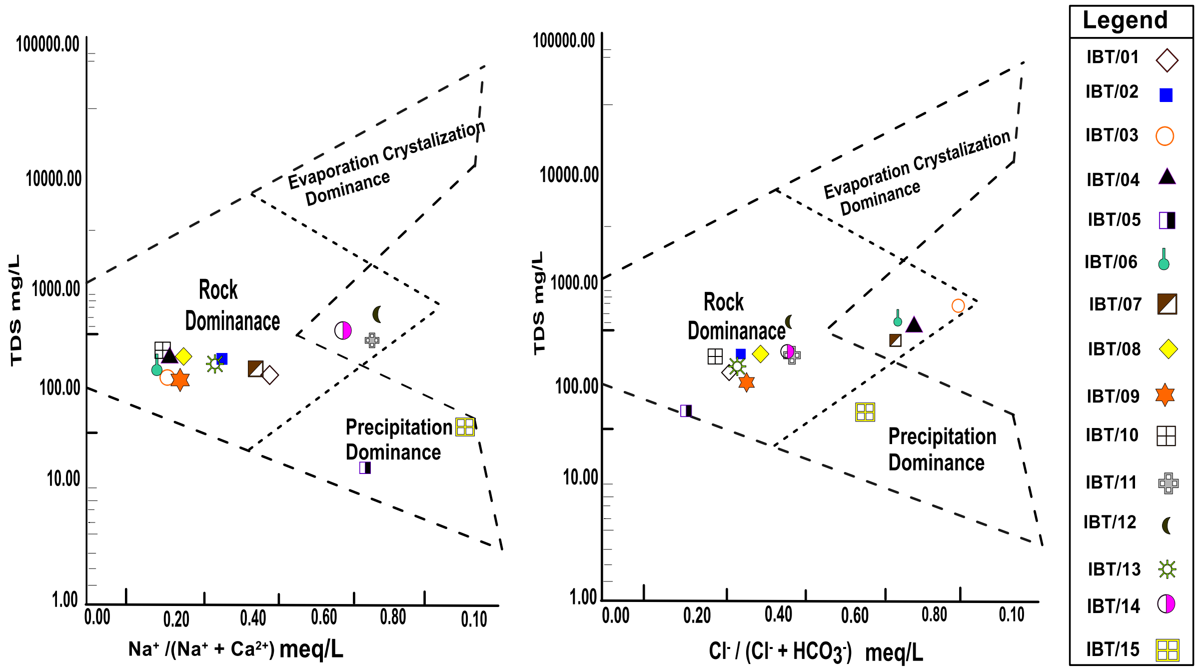

Figure 8: Gibb's Plot of Water Sampled Location of the Study Area

Piper diagram, Scholler and Durov plots were plotted using by AquaChem software. Piper (1944), Trilinear diagram was used to classify groundwater types in the area. It permits the cation and anion compositions of many samples to be presented on a single graph in which major groupings or trends in the data can be discerned visually (Freeze and Cherry, 1979). From Fig.9. it was observed that the dominant water type is SO_4^{2-}+ Mg^{2+} type.

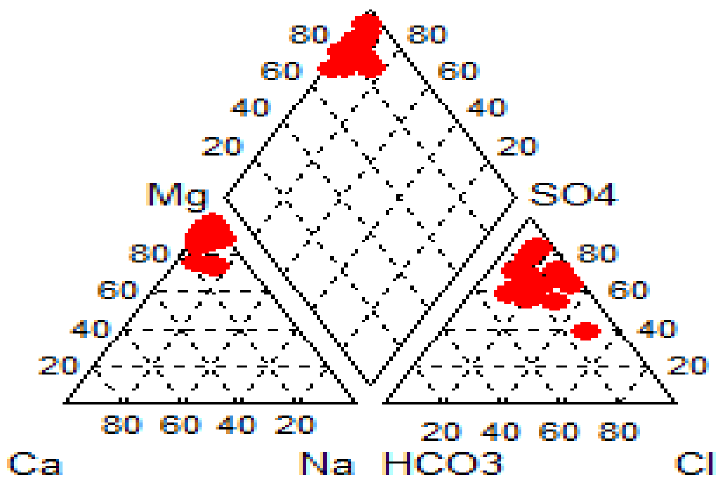

Figure 9: Piper Trilinear Plot

Fig. 10.Shows that groundwater trend is of Mg^{2+}> SO_4^{2-}>Cl^->HCO_3^->Na^+>Ca^+

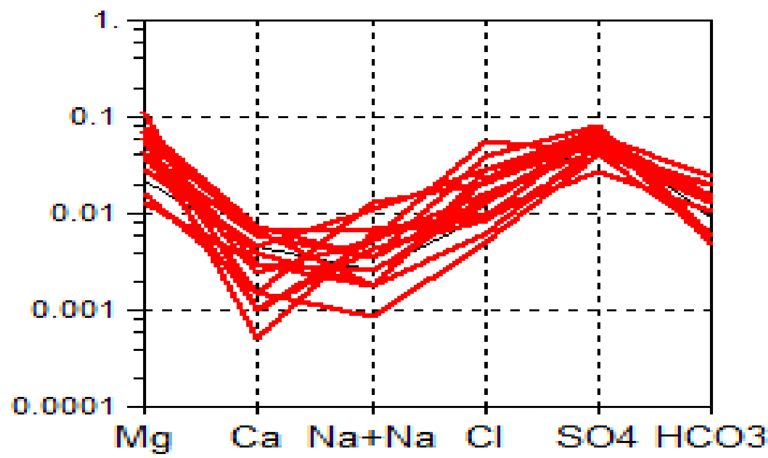

Figure 10: Scholler Diagram

From Fig. 11. It was observed that the dominant water type is SO_4^{2-}+ Mg^{2+}.

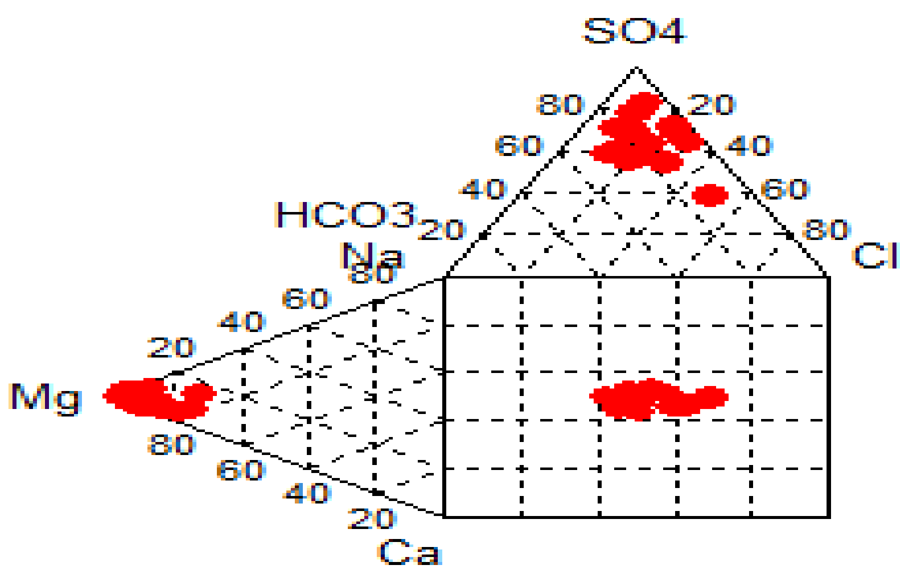

Figure 11: Durov Plot of cations and anions

Conclusion

Water is necessary for both human and plants for day to day living. Classification of water type based on PH shows that groundwater slightly acidic to basic, and are within acceptable range for irrigation purpose. Groundwater in Ibinta was evaluated for suitability for irrigation and effect of source on groundwater quality, from hydrogeochemical facies plot, the dominant water type from Piper plot is SO_4^{2-}+ Mg^{2+} type, from Scholler diagram groundwater trend in Mg^{2+}> SO_4^{2-}>Cl^- >HCO_3^->Na^+>$Ca^+$and the Wilcox diagram showed that the groundwater fell within the range of permissible to excellent. Lastly from Durov plot the dominant water type isSO_4^{2-}+ Mg^{2+}. As for irrigation parameters it was observed that parameters such as SSP, Na%, KR and TH were below the permissible limit for irrigation, based on these ground water is considered fit for irrigation. While for SAR and EC all sampled analyzed were considered fit for irrigation except sample location IBT/12 and14.

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