Analysis of Major Ion Constituents in Groundwater of Amassoma and Environs, Bayelsa State, Nigeria

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ABSTRACT

The present study focused on the hydrochemistry of groundwater in Amassoma and neighbouring communities to assess the quality ofgroundwater for determining its suitability for drinking and agricultural purposes. Groundwater samples werecollected from fourteen stations in the study area and were analysed for physico-chemical parameters such as pH, EC, TDS, sodium, potassium, calcium, magnesium, chloride, sulphate, carbonate,bicarbonate, nitrate and iron. Comparison of the analysed parameters with World Health Organization (WHO, 2006) drinking water standards shows that groundwater in the area is satisfactory for drinking purposes.The results also show that calcium concentration in two stations exceed permissible limits while iron concentration in more than 60% of the locations sampled were seen to exceed acceptable levels as per WHO standards with maximum up to 0.84mg/L. Piper trilinear diagram was plotted based on the results of the analysis for characterization of the hydrogeologic systems and classifying the different water types. Groundwater samples in the study were classified into two groups – the predominantly Calcium bicarbonate water type and the Magnesium sulphate, sodium chloride calcium bicarbonate water type based on their hydrogeochemical characteristics. In the second class all ions appear to be reasonably present in close proportions. Water of this composition is generally acceptable for domestic and industrial purposes, provided the TDS are within tolerable limits. The calcium bicarbonate waters are generally hard. The piper diagram also shows that alkali earth metals $(Ca^{2+} + Mg^{2+})$ exceed alkali metals $(Na^+ + K^+)$ while weak acids $(HCO_3^- + CO_3^{2-})$ were dominant over the strong acids $(SO_4^2 + Cl^-)$. Lastly, the groundwater chemistry was analysed to determine its suitability for agricultural purposes. The calculated values for Sodium adsorption ratio (SAR), Residual Carbonate and Percentage sodium derived from the hydrochemical data suggest that groundwater is of sufficient quality for irrigation in the area.

Keywords: Groundwater, hydrogeochemistry, major ion, water quality, Amassoma, Bayelsa State

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INTRODUCTION

The study area is located betweenlatitude 4^0 55'Nand 5^0 05'N and longitude 6^0 05'E and 6^0 20'E (Fig. 1).The area is accessible by road and approximately twenty five kilometres from Yenagoa which is the state capital. The commencement of academic activities in the Niger Delta University since 2001 has directly resulted in the steady population growth and hence the need for commensurate socio-economic infrastructural facilities including adequate water supply for domestic, agricultural and industrial use.

Water quality is as important as its quantity. This is because of the important role good or otherwise poor water quality plays in the health profile of any community. The chemical constituents of groundwater beyond certain threshold are known to cause some health risks, so supply cannotbe said to be safe if specific information on water quality which is needed for sustainableresource development and management is lacking. Generally water resource problems are of three main categories: too little water, too much water and polluted water (Adebola, 2001).

Various workers in the Niger Delta have carried out extensive work on water quality for different purposes. In the Western Niger Delta, Akpoborie and Aweto (2012) have studied the groundwater conditions in the mangrove swamp of Ughoton which revealed the preponderance of certain major ions and elevated concentrations of some heavy metals at shallow aquifer depth. Efe *et al*, (2005) investigated the seasonal variation of physiochemical characteristics in water resources quality of Warri metropolis with an overall observation that the data indicated deterioration of water quality, the pollution source, being point sources.
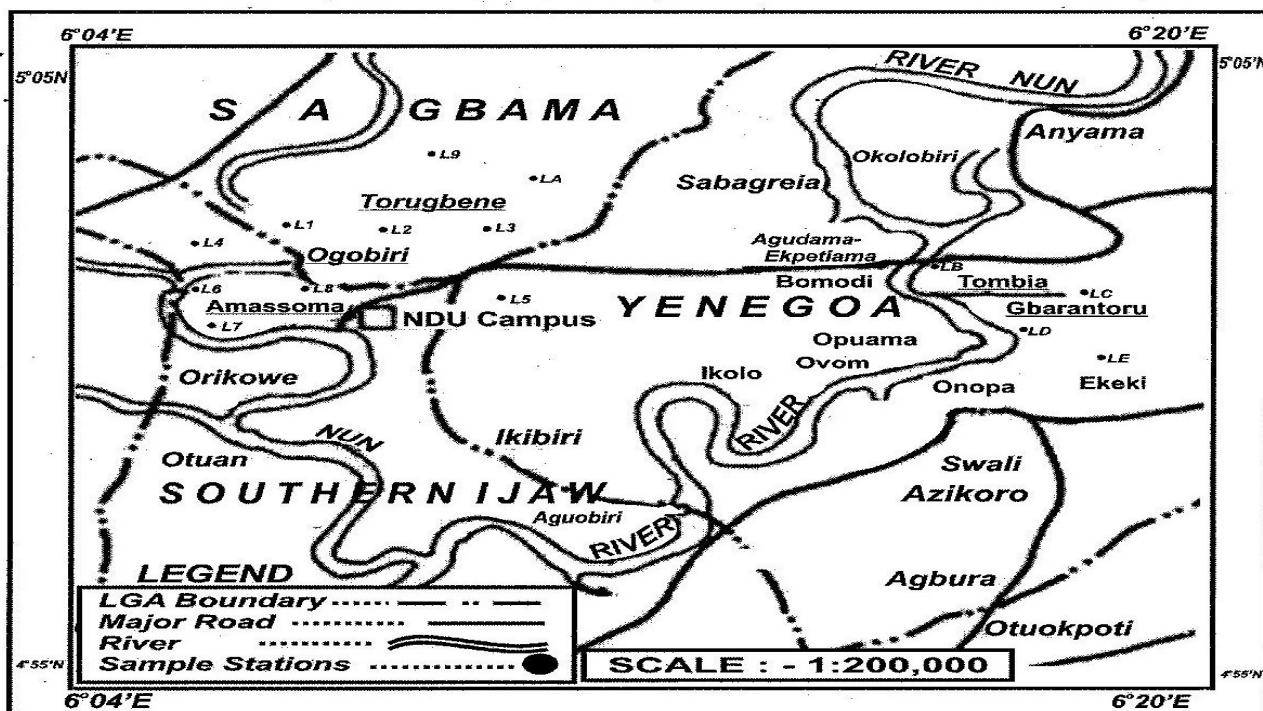

Fig 1: Map of the study Area

In the Eastern Niger Delta Nwankwoala and Udom, (2011) have studied the hydrogeochemical characteristics of groundwater resources to identify the distribution of groundwater geochemistry and hydrogeochemical evolution pattern in the area. Other workers in the Eastern Niger Delta include Udom *et al,* (1999), Amadi *et al*, (1989), and Etu-Efeotor, (1981). They acknowledged that

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groundwater quality in the area is threatened by increase in population and rapid urbanization.

In contrast to the relatively appreciable and benign attention received by the Eastern and Western Niger Delta region respectively, the Bayelsa axis is almost completely bereft of research data in terms of groundwater studies except in regional discussions of the entire Niger Delta. The objective of this study as part of effort to bridge this intellectual gap is focused on the analysis of the major constituents of groundwater in Amassoma and its environs and classifies the water in a bid to appraise the water quality and its suitability for domestic and irrigation purposes using standard scientific yardsticks.

The basin fill of the Niger Delta Basin has been described by Short and Stauble (1967), Murat (1970), among others and consists of three formations, namely, from the oldest to the youngest, the Akata Formation, Agbada Formation both of Eocene to Recent and the Miocene to Recent BeninFormation. The Benin Formation underlies much of the Niger Delta basin. The Freshwater Swamps are typically filled by a succession of thinly bedded silts and clays that are interbedded with sands (Allen, 1965).
Like places along the Nigerian coastal zonethe study area experiences a tropical climate characterized by two distinct seasons – the rainy season (April - mid August and September to early November) but at least an inch of rain is likely to fall in any of the dry months (Ofoma, *et al*, 2005).

MATERIALS AND METHODS

Groundwater samples from fourteen boreholes in and around Amassoma were collected and analysed. Samples were collected in good quality screwcapped jerry cans of 1.5 litre capacity. Sampling was carried out without adding any preservatives to avoid any form of artificial contamination and brought to the laboratory.
Physical parameters like pH, temperature and EC weredetermined at the sampling site. The chemical analysis for chloride, carbonate and bicarbonate was carried outby volumetric titration methods; while nitrate, sulphate, calcium, magnesium and iron were estimated by spectrophotometric methods and sodium and potassium by flame photometry methods**.**

RESULTS AND DISCUSSION

Table 1 illustrates the various physicochemical parameters of groundwater in the study area. Correlation matrix among twelve water quality parameters of groundwater samples is shown in Table 2. Table 3 is a characterization of groundwater of study area on the basis of piper tri-linear diagram. Classification of irrigation water on the basis of electrical conductivity (EC), percentage sodium (% Na), sodium absorption ratio (SAR) and residual sodium carbonate (RSC) are shown in Tables 4, 5, 6 and 7 respectively.

Table 1: Analytical results of physio-chemical parameters of groundwater in the study area

Bore No.	Location	Temp (^{0}C)	pH	TDS (mg/l)	EC (µS/cm)	HCO_3^- (mg/l)	CO_3^{2-} (mg/l)	NO_3^- (mg/l)	SO_4^{2-} (mg/l)	Cl^- (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Mg^{2+} (mg/l)	Ca^{2+} (mg/l)	Fe^{2+} (mg/l)
L1	Ogobiri1	28.4	6.1	201	402	52.4	4.8	0.27	6.4	20.5	42.5	4.8	13.5	21.0	0.40
L2	Ogobiri 2	27.2	5.6	518	1035	125.5	7.2	0.45	14.0	32.7	73.1	25.3	53.1	56.2	0.62
L3	Ogobiri 3	27.0	6.2	73	156	17.3	6.7	BDL	2.3	27.3	26.1	2.6	3.5	5.4	0.15
L4	Ogobiri 4	28.9	6.8	225	450	53.9	3.5	0.20	9.1	25.8	45.4	9.7	18.3	30.0	0.20
L5	Amassoma1	27.2	6.5	280	559	76.2	4.0	0.25	13.7	27.4	41.9	3.4	24.8	39.2	0.34
L6	Amassoma2	27.5	6.2	246	491	63.1	3.8	BDL	8.5	24.2	43.2	5.8	22.5	37.8	0.42
L7	Amassoma3	28.3	6.7	195	390	55.3	5.1	0.54	7.5	14.8	21.8	4.2	24.1	19.0	0.35
L8	Amassoma4	27.6	5.8	579	1158	116.4	11.0	0.18	12.2	36.5	65.1	29.0	50.7	78.2	0.27
L9	Torugbeni 1	27.8	6.5	262	523	61.8	4.2	0.39	10.9	32.1	45.6	7.5	26.3	22.7	0.84
LA	Torugbeni 2	27.1	6.2	315	631	102.9	7.6	0.65	15.6	29.0	47.5	9.8	17.5	45.3	0.45
LB	Tombia 1	28.6	6.4	308	615	93.3	5.8	0.12	6.8	25.3	34.2	17.2	20.2	36.0	0.05
LC	Tombia 2	28.4	6.1	91	182	29.7	4.5	0.38	2.1	31.2	26.0	3.1	7.1	10.6	0.20
LD	Gbarantoru 1	27.5	6.8	380	760	114.5	16.4	0.35	9.5	38.5	49.3	10.8	14.3	39.7	0.52
LE	Gbarantoru 2	28.0	6.5	187	375	43.4	8.2	0.27	7.8	22.9	37.9	5.6	12.1	28.6	0.48

BDL: Below detection limits

Groundwater chemistry

Understanding the quality of groundwater is important because it is the main factor in determining its suitability for domestic, drinking, agricultural and industrial purposes. The pH values of groundwater ranged from 5.6 to 6.8 with an average value of 6.3. This shows that the groundwater of the study area is mainly acidic in nature and all the samples were within the permissible limit prescribed by WHO. The TDS value ranged from 73 to 579 with a mean of 275.7. According to WHO the desirable limit of TDS is 500. The value of EC varied from156 µs/cm to 1158 µs/cm with an average value of 551.9µs/cm. The maximum limit of EC in drinking water is prescribed as 1500 µs/cm as per WHO standard.From the study, the average concentration of major ionsin the groundwater is in the following order Bicarbonate> Chloride > Sulphate > Nitrate for anions and Sodium > Calcium > Magnesium > Potassium for cations. Ca^{2+} value varied from 5.4mg/L to 78.2 mg/L with an average value of 33.5mg/L. The desirable limit of Ca^{2+} for drinking water is specified by WHO as 75mg/L. It is observed thatonly sample L8 exceeds this limit. Mg^{2+} concentration varied from 3.5mg/L to 53.1mg/L with a mean value of 21.9 mg/L. According to WHO the desirable value of $Mg^{2+}$is 50mg/L. From the results, samples L2 and L8 exceed the maximum permissible limit. Excess of calcium and magnesium are major contributors to hardness of water which is an undesirable effect particularly for laundry purposes. Concentration of HCO_3^- ranged from 17.3mg/L to 125.5mg/L with a mean of 71.8 mg/L. The range of permissible concentrations for HCO_3^- is not stated in the WHO 2006 guidelines for drinking water. Cl^- concentration varied between 14.8mg/L to 38.5mg/L with an average of 25.3mg/L. All samples were within the allowable limit of 250 mg/L. The NO_3^-concentrationin the groundwater samples were generally very low and range from 0.12 mg/L to 0.65mg/L with an average value of 0.34mg/L. All the

samples analysed were well below the maximum desirable limit of 50 mg/L.SO_4^{2+} values varied from 2.1 mg/L to 15.6 mg/L and are all below desirable limit based on WHO prescription. Fe^{2+} values varied from 0.08 mg/L to 0.84 mg/L, with a mean of 0.34mg/L. samples 2,6,7,9, LA, LD and LE exceed maximum permissible limit of 0.3mg/L. According to Udom *et al* (1999) and Nwankwoala (2013) exposure of water samples to air could cause ferrous (Fe^{2+}) ion in them to oxidize to ferric (Fe^{3+}) ion which would precipitate a rust-coloured ferric-hydroxide which stains plumbing fixtures, laundry and cooking utensils. Also, high iron content in water may cause staining of laundry, metal pipes for reticulation and scaling in pipes. It may also give undesirable taste (Etu-Efeotor, 1981; Ibe and Sowa, 2002). According to Ngah & Allen, (2005), deposit of ferruginous materials in a water distribution system can contribute to the growth of iron bacteria which in turn could cause further water quality deterioration by producing slimes or objectionable odours, frothing tastes, colour as well as increase in turbidity. The primary source of the iron contamination is geologic. According to Etu-Efeotor (1981), the laterites in the Benin Formation are ferruginous and probably stained by limonite and goethite. Iron can easily be leached from these materials into the groundwater system. WHO (2006) stated that iron may also be present in drinking water as a result of the use of coagulants and the corrosion of steel and cast iron pipes during water distribution. Aeration, followed by sedimentation and filtration will usually remove iron from the water. Alternatively, iron can be prevented from coming out of solution by adding a small amount of sodium hexametaphosphate to the water. This polyphosphate stabilizes the iron and delays its precipitation (Udom *et al*, 1999). Regular flushing of borehole and distributive systems can help control build-up of ferruginous materials.

Correlation:
The correlation coefficients (r) among twelve water quality parameters namely pH, EC, TDS, Ca^{2+},Mg^{2+}, Na^+, K^+, Fe^{2+}, HCO_3^{2-}, NO_3^-, SO_4^{2-}, and Cl^- were calculated for correlation analysis. Interpretation of correlation gives an idea of quick water quality monitoring method. According to Table 2 the EC and TDS shows good positive correlation with Chloride and Sulphate and also exhibit high positive correlation with bicarbonate and all the cations with the exception of iron. The correlation between Na^{2+}-Cl^- , Na^{2+}-HCO_3^-, Na^{2+}-SO_4^2, Ca^{2+}- Cl^-, Ca^{2+}-HCO_3^-, and Ca^{2+}-SO_4^{2-} were all positive and above 0.5. However the P^H values in the analysis showed negative correlation with the concentration of all the parameters except for NO3, Ca, and Mg while the correlation between NO_3^- -EC, NO_3^--TDS, NO_3^- -K and NO_3^- -Mg are also negative.

Table 2: Correlation of physico-chemical parameters of groundwater

	pH	TDS	EC	HCO3	NO3	SO4	Cl	Na	K	Mg	Ca
TDS	-0.595										
EC	-0.592	0.9998									
HCO3	-0.4722	0.8600	0.8572								
NO3	0.110	-	-	-							

	8	0.0415	0.0418	0.0127							
SO$_4$	-0.4459	0.5428	0.5412	0.5849	0.0163						
Cl	-0.235	0.6397	0.6358	0.652	0.0252	0.4318					
Na	-0.6297	0.8079	0.8145	0.6415	0.0322	0.5568	0.6500				
K	-0.4788	0.8832	0.8813	0.6824	-0.0921	0.3440	0.4748	0.6594			
Mg	0.5386	0.7914	0.7955	0.5182	-0.0353	0.4359	0.3100	0.6638	0.7594		
Ca	0.6265	0.8961	0.8932	0.7500	0.0562	0.5861	0.5572	0.7131	0.7975	0.6664	
Fe	-0.1357	0.2471	0.2456	0.3406	0.0673	0.3491	0.2728	0.3687	0.0593	0.1499	0.1593

Piper Diagram

Trilinear plotting systems developed by Piper (1944) were used in the study of the water chemistry and quality. Piper diagrams are a combination of cation and anion triangles that lie on a common baseline. A diamond shape between them is used to replot the analyses as circles whose areas are proportional to their TDS. The position of an analysis that is plotted on a piper diagram can be used to make a tentative conclusion as to the origin of the water represented by the analysis. The diamond part of a piper diagram may be used to characterize different water types. Generally, groundwater can be divided into four basic types according to their placement near the four corners of the diamond. Water that plots at the top of the diamond is high in ca^{2+} + Mg^{2+} and Cl^-+ SO_4^{2+}, which results in an area of permanent hardness. Water that plots near the left corner is rich in Ca^{2+} + Mg^{2+} and HCO_3^- and is the region of water of temporary hardness. Water plotted at the lower corner of the diamond is primarily composed of alkali carbonates (Na^++ K^+ and HCO_3-+CO_3^{2-}). Water lying near the right-hand side of the diamond may be considered saline (Na^++ K^+ and Cl^-+ SO_4^{2+}). The water types in the study area were thus designated according to the area in which they occur on the diagram segments (Fig.3). These diagrams reveal the analogies, dissimilarities and different types of waters in the study area, which are shown in Table 3.

The concept of hydrochemical facies presented by Walton (1970) was used to understand and identify the water composition in different classes based on the dominance of certain cations and anions in solutions (Fig. 2). It clearly explains the variation or domination of cation and anion concentration in the study area.

According to Table 3 alkaline earth type of water ($Ca^{2+} + Mg^{2+}$) exceed the alkalis ($Na^+ + K^+$) whereas for the anions, the weak acids ($HCO_3^- + CO_3^{2-}$) exceed strong acids ($Cl^- + SO_4^{2-}$). Nearly 75% samples (L1, L2, L5, L6, L7, L8, LA, LB, LD, LE) show secondary alkalinity where chemical properties are dominated by alkali earths and weak acids. Only one sample (LC) shows primary salinity (dominated by ions, alkali and strong acids). Not a single sample showed either primary alkalinity or secondary salinity. Lastly 25% samples (L3, L4 and L9) fall in the diamond shape division where no cation-anion pair exceeds 50%.

Irrigation water quality

Electrical conductivity (EC) is a good measure of salinity hazard to crops. Excess salinity reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil (Saleh *et al.,* 1999).

Sodium Absorption Ratio (SAR)

Based on the sodium absorption ratio SAR, all the samples collected and analysed in the study were within the permissible range and are thus suitable for irrigation under normal conditions (Table 4). SAR is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of sodium hazard to crops. According to Karanth (1987), SAR can be estimated by the formula-

SAR = $(Na+) / [\frac{1}{2}(Ca^{2+} + Mg^{2+})]^{\frac{1}{2}}$ where all ionic concentrations are expressed in meq/L. SAR values ranges from 0.96 to 2.14. All the sampling stations fall in the excellent category because none of the samples exceeded the value of SAR = 10 (Table 6). The classification system to evaluate the suitability of water for irrigation use can be determined by graphically plotting these values (EC and SAR) on the US salinity diagram (Richards, 1954). The plots of groundwater chemistry of study areas in the USSL diagram are shown in Figure 3. The plot illustrates that two groundwater samples (L3, LC) fall in the field of C1S1, while Seven samples (L_1, L_4, L5, L6, L7, L9, LA, LB, LE) fall in the field of C2S1 indicating that the irrigation quality of the sampled groundwater was good and fair respectively in these study areas. Three samples (L2, L8 and LD) fall in C3S1 type indicating high salinity and low alkalinity in water, which can be used for irrigation on almost all types of soil with little danger of exchangeable Sodium (Fig. 4).

Percentage Sodium (% Na)

The sodium in irrigation water is usually expressed in% Na. Generally maximum of 60% sodium is permissible for irrigation water. % Na can be determined by using the formula (Wilcox, 1955) -

% Na = $(Na^+ + K^+) 100 / (Ca^{2+} + Mg^{2+} + Na^+ + K^+)$ where all the ionic concentrations are expressed in meq/L. The value of % Na varies from 29.7 to 68.8. According to Table 5, the entire groundwater samples fall within excellent to permissible categories for irrigation with respect to % Na.
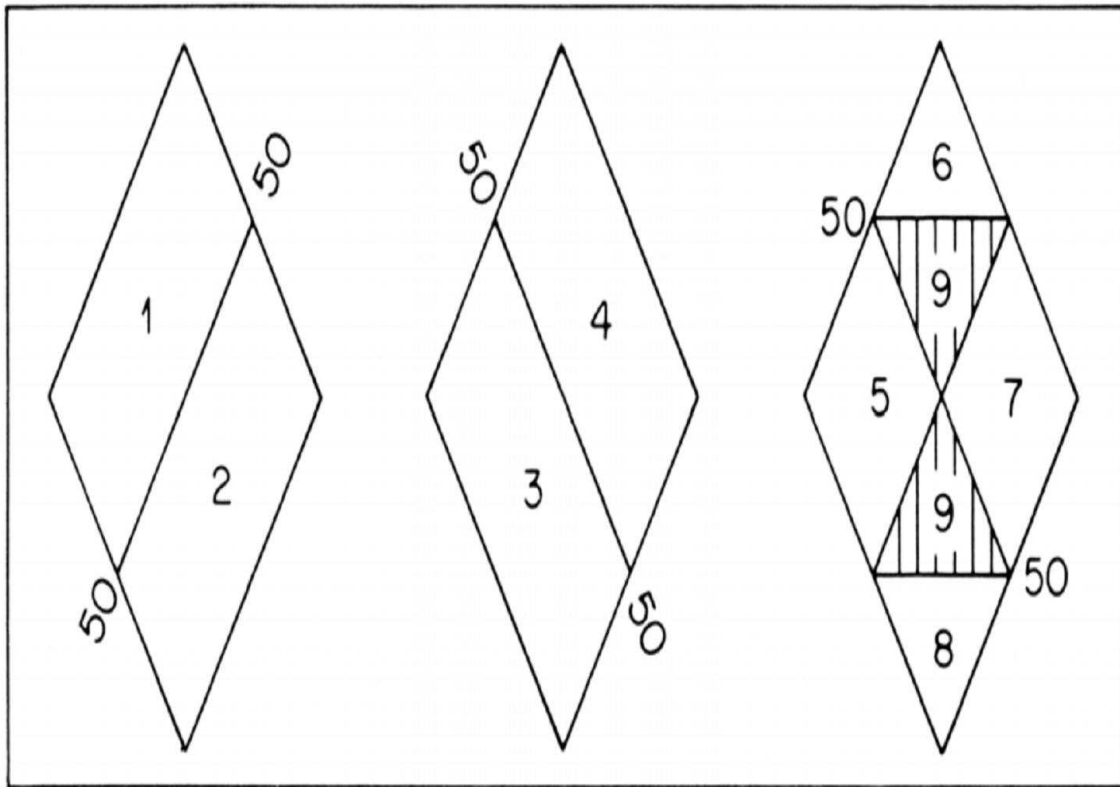
Residual Carbonate (RSC)

RSC has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose (Eaton 1950) and has been determined by the formula-RSC = $(CO^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$ where all the ionic concentrations are reported in meq/L. The classification of irrigation water according to the RSC values is presented in Table 8. According to the US Department of Agriculture, water having more than 2.5 meq/L of RSC is not suitable for irrigation purposes while those having 1.25 - 2.5 meq/L are marginally suitable and those less than

1.25meq/L are safe for irrigation. The results for the study (Table 7) show that all the samples were good for irrigation.
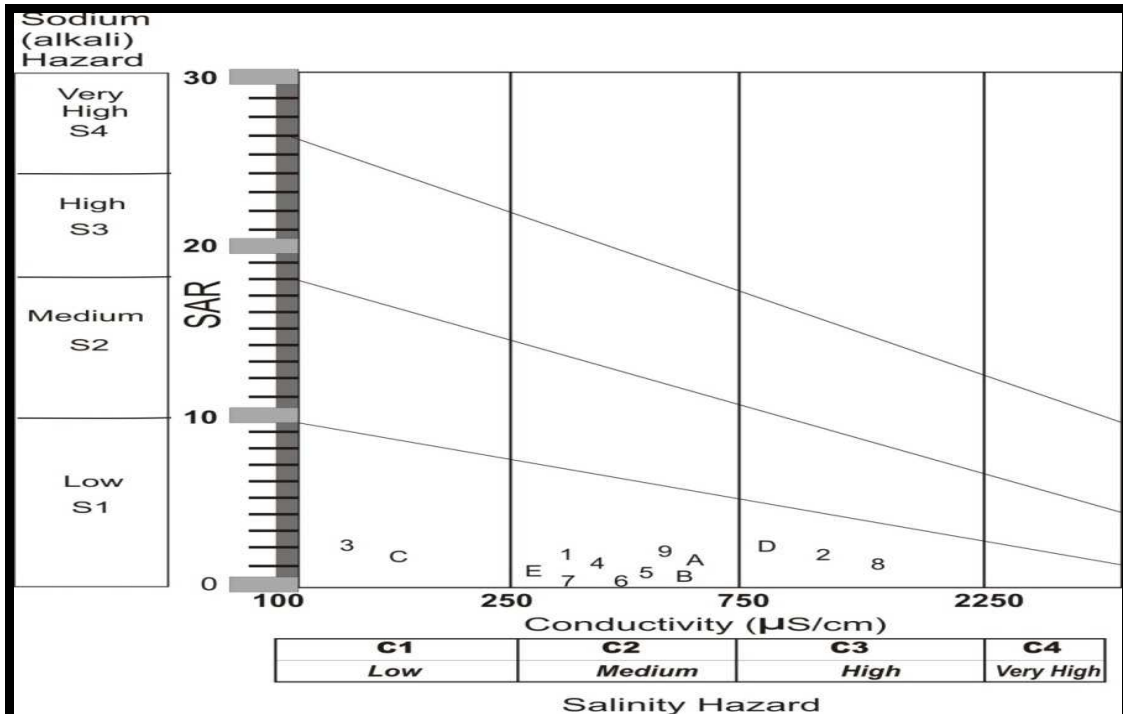

Figure 2: Trilinear Piper Diagram

Figure 3: Subdivisions of the diamond-shaped field of the Piper diagram (9 facies)

Figure 4: Classification of irrigation waters using U.S. Salinity diagram

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Table 3: Characterization of groundwater of study area on the basis of Piper tri-linear diagram

Subdivision of the diamond	Characteristics of corresponding subdivision of diamond shaped field	Samples
1	Alkali earths (Ca^{2+} + Mg^{2+}) exceed alkalis (Na^+ + K^+)	All (except L3 and LC)
2	Alkalis exceeds alkali earths	2 (L3 and LC)
3	Weak acids (CO_3^{2-} + HCO_3^-) exceed strong acids (SO_4^{2-} + Cl^-)	All (except L4, L9 and LC)
4	Strong acids exceed weak acids	3 (L4, L9 and LC)
5	Carbonate hardness (secondary alkalinity) exceeds 50% (chemical properties are dominated by alkali earths and weak acids)	All (except L3, L4, L9, LC)
6	Non-carbonate hardness (secondary salinity) exceeds 50% (chemical properties are dominated by alkali earth and strong acids	Nil
7	Non-carbonate alkali (primary salinity) exceeds 50% (chemical properties are dominated by alkalis and strong acids)	1(LC)
8	Carbonate alkali (primary alkalinity) exceeds 50% (chemical properties are dominated by alkalis and weak acids)	Nil
9	No cation–anion pair exceeds 50%	3 (L3, L4, L9)

Table 4: Quality of Irrigation Water based on Electrical Conductivity

Salinity hazard class	Electrical conductivity (µS/cm)	Characteristics	Samples
Low	0 – 250	Low-salinity water can be used for irrigation on most soil with minimal likelihood that soil salinity will develop.	2 (L3 and LC)
Medium	250 – 750	Medium-salinity water can be used for irrigation if a moderate amount of drainage occurs.	9 (L1, L4, L5, L6, L7, L9, LA, LB and LE)
High	750 – 2250	High-salinity water is not suitable for use on soil with restricted drainage. Even with adequate drainage, special management for salinity control may be required.	3 (L2, L8 and LD)
Very high	> 2250	Very high-salinity water is not suitable for irrigation under normal conditions.	Nil

Table 5: Quality of groundwater based on % Sodium

% Na	Water quality	Samples
< 20%	Excellent	Nil
20 - 40%	Good	7 (L2, L5, L6, L7, L8, LA and LB)
40 - 60%	Permissible	5 (L1, L4, L9, LD and LE)
60 - 80%	Doubtful	2 (L3 and LC)
> 80%	Unsuitable	Nil

Table 6: SAR values can then be compared to characteristics of the four sodium-hazard classes as follows

SAR	Water-suitability for irrigation
0 - 10	Suitable for all types of soils except for those crops which are highly sensitive to Sodium.
10 - 18	Suitable for coarse textured or organic soil with good permeability. Relatively unsuitable in fine textured soil.
18 - 26	Harmful for almost all types of soils. Requires good drainage, high leaching and gypsum addition.
> 26	Unsuitable for irrigation

Table 7: Quality of groundwater based on residual Sodium Carbonate

RSC	Water quality	Samples
< 1.25	Good	All samples
1.25 - 2.5	Doubtful	Nil
> 2.5	Unsuitable	Nil

Table 8: The Value of EC, % Na, SAR and RSC

Sample	% Na	SAR	RSC
L1	47.5	1.78	Nil
L2	34.6	1.67	Nil
L3	68.1	2.14	0.1
L4	42.3	1.61	Nil
L5	29.7	0.86	Nil
L6	39.6	1.35	Nil
L7	35.2	0.96	Nil
L8	37.2	1.63	Nil
L9	49.3	1.87	Nil
LA	37.9	1.52	Nil
LB	35.5	1.12	Nil

LC	68.8	1.51	Nil
LD	43.2	1.69	Nil
LE	42.3	1.35	Nil

CONCLUSION

The physico-chemical characteristics of selected groundwater parameters have been determined in the study. The results of the analysis show that most of the parameters like pH, sodium, potassium, magnesium, carbonate, bicarbonate, chloride, nitrate, sulphate are within the permissible limits stipulated by WHO. However, TDS and calcium values in one and two stations respectively exceed permissible limits while iron concentration in about 65% of the locations sampled were seen to exceed acceptable levels as per WHO standards. Piper trilinear diagram was plotted based on the results of the analysis for separating the different watertypes, classification and characterization of the hydrologic systems. Groundwater samples in the study were classified into two groups – the predominantly Calcium bicarbonate water type and the Magnesium sulphate, sodium chloride calcium bicarbonate water type based on their hydrogeochemical characteristics. The second water type is the predominantly Calcium bicarbonate water. In the second class all ions appear to be reasonably present in close proportions. Water of this composition is generally acceptable for domestic and industrial purposes, provided the TDS are within tolerable limits. The calcium bicarbonate waters are generally hard and are attributed to the environment of deposition of the sands, and the matrix binding the sands being calcareous, or due to infiltration of carbon dioxide rich rain-water derived from the atmosphere.The piper diagram also shows that alkali earth metals $(Ca^{2+} + Mg^{2+})$ exceed alkali metals $(Na^+ + K^+)$ while weak acids $(HCO_3^- + CO_3^{2-})$ were dominant over the strong acids$(SO_4^2 + Cl^-)$. Lastly, the groundwater chemistry was analysed to determine its suitability for irrigation. The Sodium adsorption ratio (SAR), Residual Carbonate and percentage sodium calculated from the hydrochemical data suggest that groundwater is of sufficient quality for irrigation in the area.

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