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Quality Assessment of Groundwater from Avenorfeme: Akatsi District, Ghana

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Abstract:

An assessment of the quality of groundwater from the shallow unconfined aquifers of the Avenorfeme and surrounding villages in the Akatsi South District in the Volta Region of Ghana has been conducted. A groundwater classification scheme has been developed using water quality index (WQI) modified for the case of the study area. In calculating WQI, the following were considered, pH, sodium, potassium, calcium, magnesium, bicarbonate, chloride, nitrate, sulphate, total dissolved solids, and fluorides have been considered. On the basis of the computed WQI, groundwater fell within the 'Excellent', 'Good', 'Poor' and 'unsuitable for drinking' categories. This study showed that the salinity of groundwater in the area is largely attributed to mineral weathering leading to evolution of predominantly intermediate to high salinity Na-Cl water types. On basis of salinity hazard, most of the waters are not suitable for irrigation in the area. Based on total hardness of water, the groundwater in the area is permanently hard.

Keywords: Groundwater, Akatsi district, Volta, Water Quality Index, SAR

1. Introduction

In Ghana, it appears groundwater is increasingly gaining eminence as an alternative source of water in both rural and urban communities for various uses. This is because, aquifers are found to underlie almost all communities in Ghana, hence, groundwater can easily be abstracted at relatively shallow depths. In addition, groundwater in general is relatively cleaner and does not need extensive treatment before use. Lastly, most surface water bodies run out during the long spell of dry season (Yidana S. M., 2010).

It is a fact that many stakeholders, including government agencies, non-governmental organizations and individuals are involved in the provision of the amenity. In the same vein, Life Time Well (LTW), a non-governmental organization provided bore-holes for the people of Avenorfeme and its environs as an alternative source of drinking water. However, the consumers were sceptical about the quality of the resource as they complained of high salinity of some of the borehole waters.

The objective of the present work is to study the physicochemical, and major ion chemistry (hydrochemistry) of groundwater in the Avenorfeme area in the Akatsi South District in the Volta region of Ghana and also evaluate its suitability for domestic and agricultural uses. In this case the methods proposed by (Piper, 1944), as well as (Richards, 1954) US Salinity Laboratory (USSL) classifications and Water Quality Index (WQI) have been used to study critically the geo-chemical characteristics of the groundwater of the study area. Physicochemical parameters of groundwater play a significant role in classifying and assessing water quality. Hydrochemical study reveals quality of water suitable for irrigation, drinking and industrial purposes whereas hydrochemistry classification throws light on the concentration of various predominant cations, anions and their interrelationships.

2. The Study Area

The study area is Avenorfeme and its environs in the Akatsi South District in the Volta Region of Ghana (Fig.1). The topography of the area is low-lying coastal plain with a general elevation of the land averaging 10-50 meters above sea level, and a peculiar coastal savanna soil and tropical black earth. The area is drained by rivers and creeks, such as Tordzie, Agblegoboe and Wowoe which empty their waters into the Keta and Avu lagoons. It falls within the coastal savanna equatorial climatic regime characterized by high temperatures (min: 21° C max: 34.5° C), high relative humidity (85%) and moderate to low rainfall regime (1,084 mm) with distinct wet and dry seasons. The area experiences two major seasons. The rainy season exhibits double maxima: the main rainy season occurs between April and July, whilst the minor one falls between September and October of every year. The vegetation of the district is made up of coastal savanna. The area is underlain by Dahomeyan supergroup at the north and Cenozoic/Tertiary sedimentary basin at the south. The northern part is controlled by intermediate gneiss-granitoid terrain, mainly biotite and biotite amphibole gneiss. To the south, the area is dominated with arenaceous and argillaceous sediment, locally gravel.



Figure 1: Map of study area

3. Materials and Method

Samples were collected from boreholes in Avenorfeme in the areas of Fiato, Biese, Kpogedi (market), and Health centre. Some were as well taken from Afeyime, Dagbametey, Esusukofe, Dzuefe and Avenorpedo – all towns in Akatsi district. All samples were collected during three sampling campaigns undertaken in 2011.

Physical parameters such as electrical conductivity (EC), total dissolved solids (TDS) and pH of the samples were measured on the field using portable EC and pH Hatch meters. The boreholes were purged until stable readings for the physical parameters were obtained.

Samples were subsequently filtered through 0.45 micron membranes and collected in acid-washed, well-rinsed polyethylene bottles. The samples were collected in duplicates and filtered for anion analysis.

Chemical analyses of the water samples were performed at the National Nuclear Research Institute at Ghana Atomic Energy Commission. Calcium and magnesium ions were analyzed using Varian AA240 Fast Sequential Atomic Absorption Spectrometer. Sodium and potassium ions were measured using flame emission photometer (Sherwood model 420). The phosphate, nitrite and nitrate ions were analyzed using a UV-Visible spectrophotometer (Shimadzu: model UV-1201). The chloride and sulphate ions concentrations in the water samples were determined by titration. Fluoride and turbidity were measured using HACH DR/890 colorimeter whilst salinity was measured with HATCH senSion 5 conductivity meter.

4. Results and Discussions

4.1. General Parameters

The pH of the groundwater in the study area varied from 5.37 at Dagbametey to 7.48 at Avenorfeme with mean and median values of 6.40 and 6.30 respectively. Thus, 80% of the samples fell within the natural water pH range of 4.5–7.0. However, the WHO,(2003) recommended pH range for water potability is 6.5-8.5. These water samples could be described as moderately acidic waters except those at Kpogedi and Avenorfeme.

The conductivity of water ranged from 426.00 to 20500 $\mu\text{S cm}^{-1}$ with mean and median values of 3850.90 and 1969.00 $\mu\text{S cm}^{-1}$ respectively. Only boreholes at Dagbametey, Dzuefe and Avenorfedo had values below the standard limit of 1000 $\mu\text{S cm}^{-1}$.

The total dissolved solids (TDS) in the groundwater vary from 206.00 at Dzuefe to 11790.00 mg/L at Health Centre. The mean TDS was 2095.10 mg/L. Areas of low TDS are said to be the recharge areas and normally referred to as young waters, whereas areas of high TDS are described as discharge areas and referred to as old waters.

(Davis, 1966) classified groundwater with TDS values within the range 0–1,000 mg/L as fresh, 1,000–10,000 mg/L as brackish, 10,000–100,000 mg/L as saline water and more than 100,000 mg/L as brine. On the basis of this classification, samples from Dagbametey, Esusukofe, Dzuefe, Avenorfeme and Avenorfedo can be described as fresh waters.

Turbidity has been measured in all samples and it ranged from 0.0 to 3.0 FAU (Table 1), which is below 5.0 FAU WHO (2003) recommended limit.

Location	pH	EC ($\mu\text{S/cm}$)	TDS (mg/L)	Sal (%)	TH (mg/L)	Turbidity (FAU)
Fiato	6.55	3490	1798	1.8	638	1.0
Biase	6.24	2355	1195	1.2	313	1.0
Kpogedi	7.24	4350	2260	2.3	1738	0.0
Afeyime	6.52	3110	1593	1.6	624	3.0
Heath Centre	5.92	20500	11790	12.2	7600	1.0
Dagbametey	5.37	752	366	0.4	119	3.0
Esusukofe	6.31	1394	690	0.7	400	1.0
Dzuefe	6.05	426	206	0.2	132	0.0
Avenorfeme	7.48	1583	787	0.8	160	0.0
Avenorfedo	5.96	549	266	0.3	144	0.0
Min	5.37	426.00	206.00	0.2	119.00	0.0
Max	7.48	20500.00	11790.00	12.20	7600	3.0
Mean	6.40	3850.90	2095.10	2.15	1186.80	1.0
Median	6.30	1969.00	991.00	1.00	356.50	1.0

Table 1: Physical parameters and statistical summaries of the groundwater samples

4.2. Hydrochemical Facies

Concentration of major ions (Ca^{2+} , Mg^{2+} , Na^+ and K^+ , HCO_3^- , Cl^- , SO_4^{2-} , NO_3^-) were also generally low (Table 2). To verify the analytical error of analyzed ion concentrations, electroneutrality (ionic balance) was computed by using the expression:

Electroneutrality = $\frac{|CAT-AN|}{CAT+AN} \times 100$, where CAT represents the cation sum and AN the anion sum (in meq/L).

Location	Na ⁺ (mg/L)	K ⁺ (mg/L)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Cl ⁻ (mg/L)	HCO ₃ ⁻ (mg/L)	NO ₃ ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	F ⁻ (mg/L)
Fiato	307.0	52.0	87.2	102.0	699.8	156.1	0.4	62.0	0.4
Biase	270.5	16.1	87.2	23.2	489.9	78.0	0.2	34.4	0.3
Kpogedi	494.0	17.0	112.8	353.8	1549.8	304.8	0.1	50.4	0.4
Afeyime	380.0	9.0	134.4	70.0	749.8	183.6	0.1	128.1	0.4
Heath Centre	3790.0	28.0	1299.2	1057.8	9073.4	251.2	0.1	490.7	0.8
Dagbametey	126.0	1.6	27.2	12.4	209.0	14.6	0.6	31.9	0.1
Esusukofe	146.0	3.0	70.4	54.5	350.9	82.9	0.6	57.5	0.1
Dzuefe	57.7	4.5	12.8	24.3	150.0	29.3	0.6	28.6	0.1
Avenorfeme	329.0	18.3	12.8	31.1	269.9	382.8	0.5	65.9	0.5
Avenorfedo	88.6	6.3	24.0	20.4	214.6	34.1	0.6	27.8	0.0
Statistics									
Min	57.7	1.60	12.80	12.40	150.00	14.63	0.08	27.80	0.04
Max	3790.0	52.00	1299.20	1657.80	9073.40	382.82	0.64	490.70	0.79
Mean	598.88	15.58	186.80	174.75	1375.40	151.75	0.38	97.73	0.30
Median	288.75	12.55	78.80	42.80	420.40	119.48	0.47	53.95	0.32

Table 2: Shows major cations and anions in groundwater

The ionic balances for the analytes varied from -2.1 to 8.3%, though only 30% of the samples had ionic balance within $\pm 5\%$. Ionic balances outside $\pm 5\%$ may be attributed to different methods employed in measuring major ion concentrations. For this work though, ionic balance of $\pm 10\%$ was considered acceptable.

These chemical compositions of groundwater (borehole samples) from the study area are also shown on the Stiff diagrams in Fig.2a-j, so as to delineate hydrochemical facies of the water samples. In the cation plot field, the samples plotted mainly towards the Na corner suggesting alkali metal (Na) exceeds alkaline earths (Mg and Ca). Nonetheless, in the anion plot field the samples plotted towards the Cl corner indicating Cl as the predominant anion. Thus, strong acid anions exceed weak acid anions. Only one sample plotted towards the HCO₃⁻ corner.

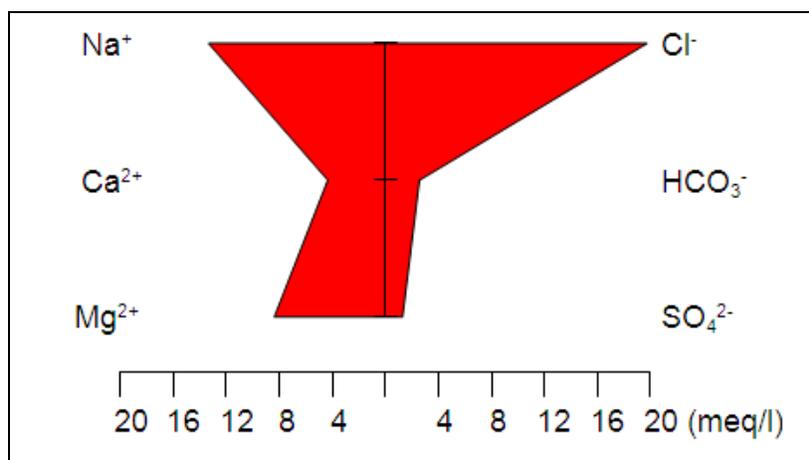


Figure 2a: Stiff diagram for Fiato

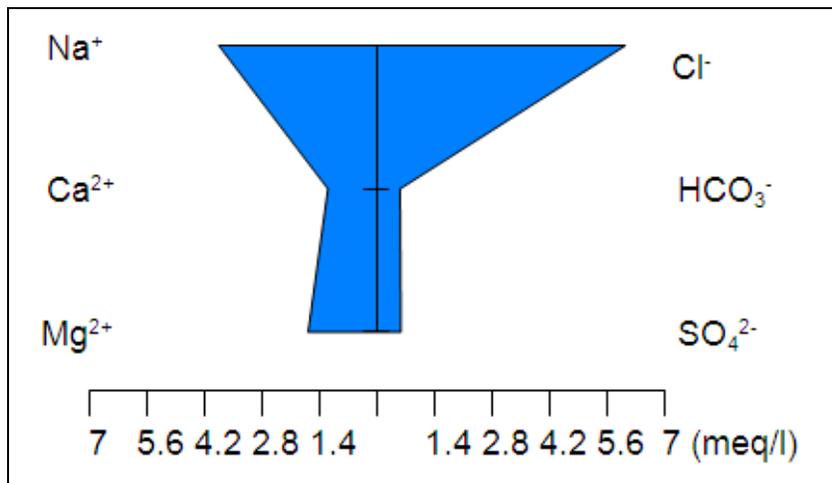


Figure 2b: Stiff diagram for Avenorpedo

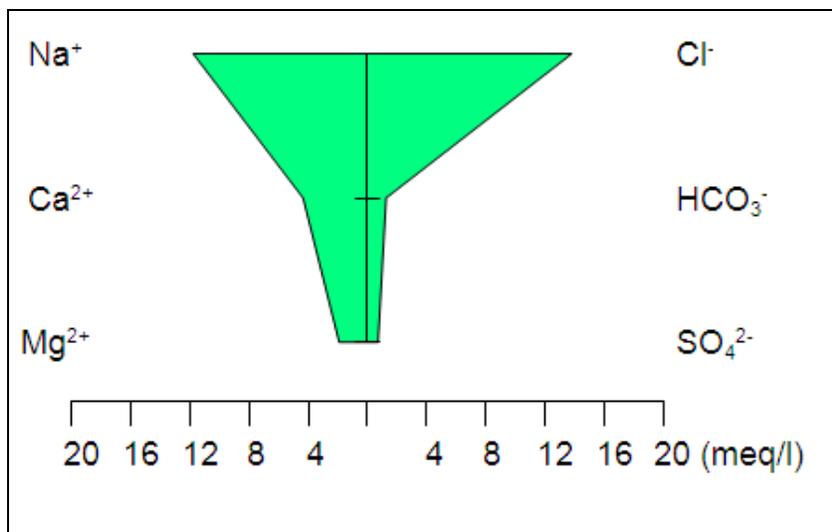


Figure 2c: Stiff diagram for Biase

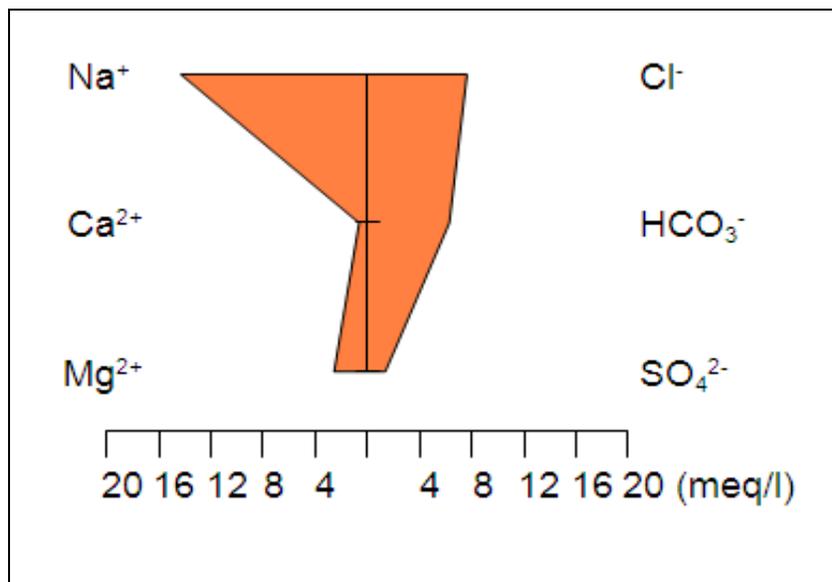


Figure 2d: Stiff diagram for Avenorpeme

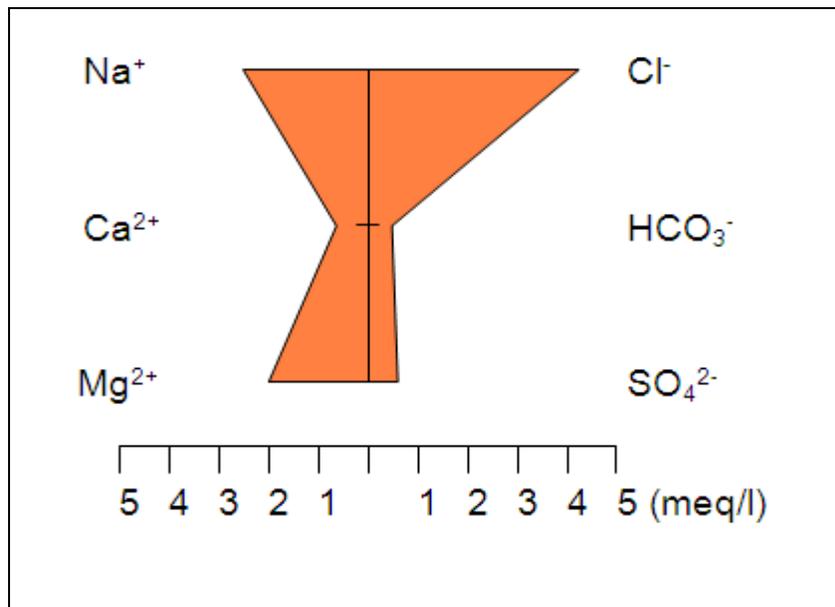


Figure 2e: Stiff diagram for Dzuefe

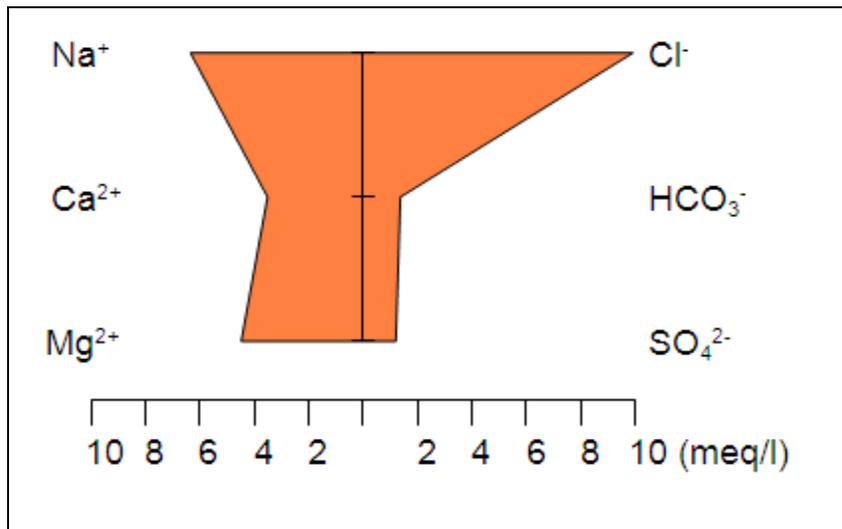


Figure 2f: Stiff diagram for Esusukofe

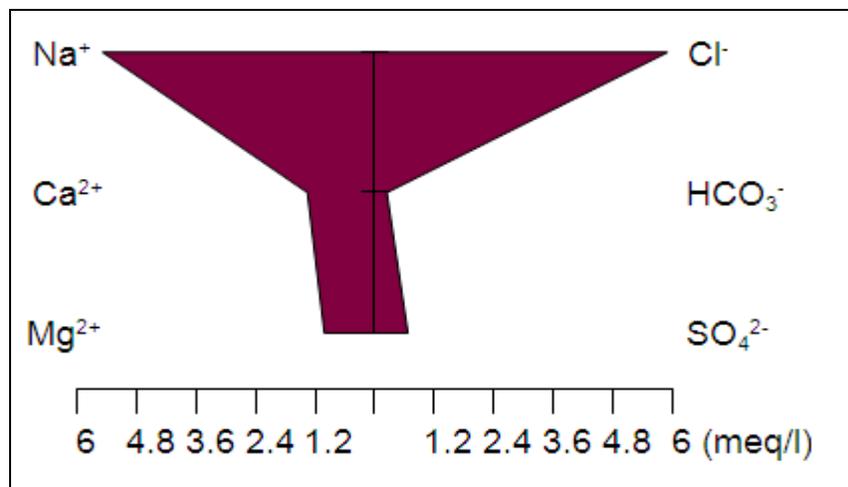


Figure 2g: Stiff diagram for Dagbamatey

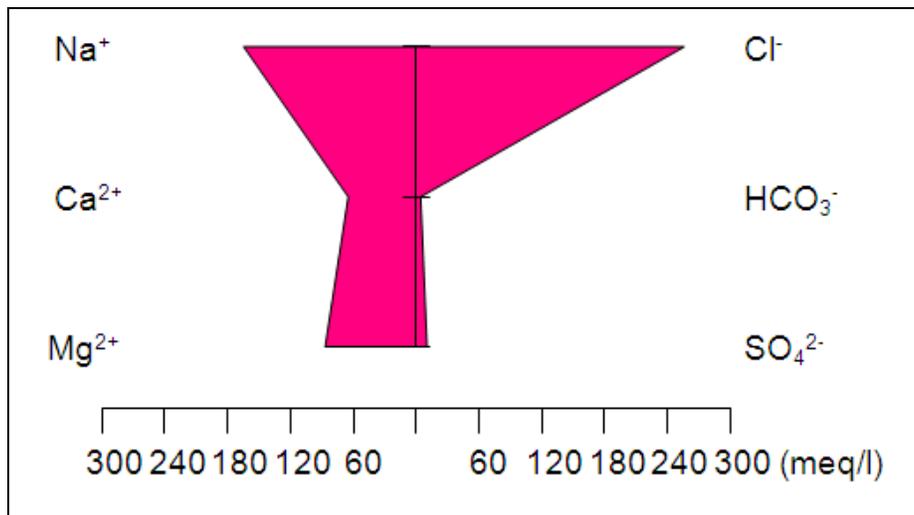


Figure 2h: Stiff diagram for Health centre

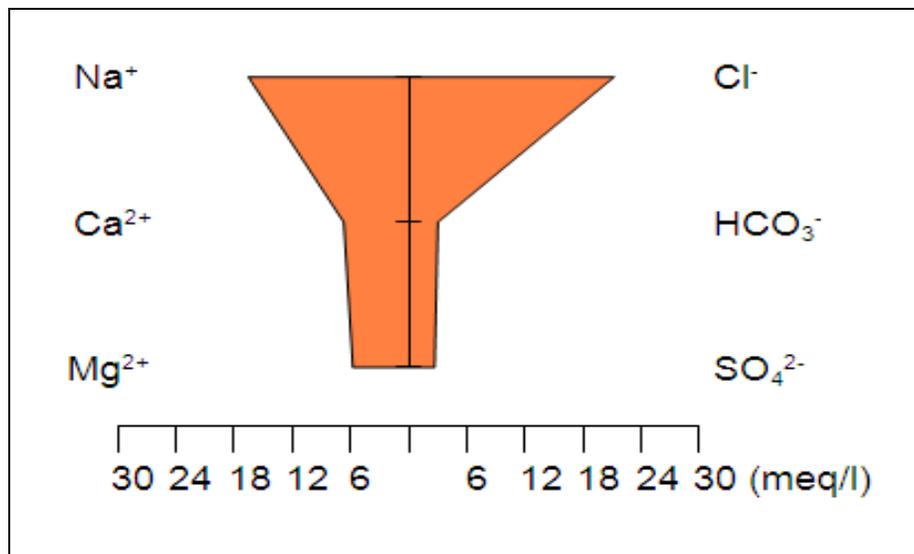


Figure 2i: Stiff diagram for Afeyime

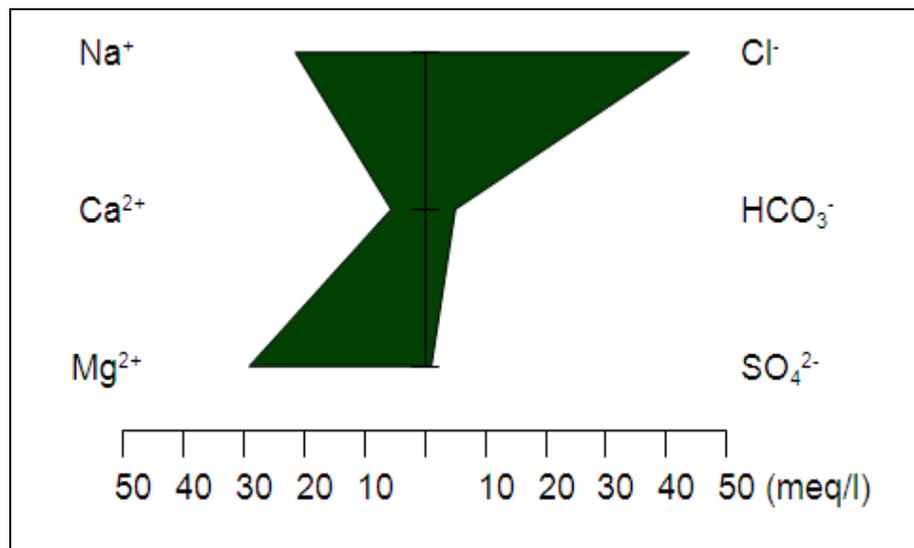
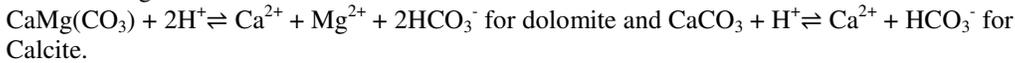


Figure 2j: Stiff diagram for Kpogedi

From the Stiff diagrams, three principal hydrochemical water types have been delineated. Waters at Kpogedi and Avenorfeme were identified as Mg-Cl and Na-HCO₃ respectively. The rest were all Na-Cl water types. Na-HCO₃ water type suggests there is base-exchanged aggressive recharging alkali carbonates water. Chemical evolution of Na-HCO₃ water type in the area may not be as a result of simple mineral dissolution and precipitation. Simple mineral dissolution can be ruled out because sodium carbonate minerals rarely occur and are unlikely to exist in the bedrock lithology in the study area (Mayo, 2000). The solute composition of these waters may be the result of a series of interrelated and cascading chemical reactions. That is, CO₂ acquired from the soil zone or from other sources react with groundwater according to:



The groundwater then approached or attained carbonate mineral saturation by dissolving dolomite and calcite in the soil and bedrock in the recharge area as:



Bicarbonate ion (HCO₃⁻) and Na⁺ ion dominated water normally indicates ion-exchanged waters, although the generation of CO₂ at depth can produce HCO₃⁻ where Na⁺ is dominant under certain circumstances (Winograd, 1974). Garrels and Mackenzie (1967) pointed out that meteoric water dissolving Na from Na-bearing silicates would produce NaHCO₃ water type. Therefore, albite dissolution would have also probably produced NaHCO₃ water type.

The Na-Cl water types suggest end-product water (saline water). Chloride ion is a widely distributed element in all types of rocks in one or more other forms. Its affinity towards sodium is high, therefore, its concentration is high in ground waters, where the temperature is high and rainfall is less. Soil porosity and permeability also have a key role in building up the chlorides concentration (Chanda, 1999)

4.3. Mechanisms Controlling Groundwater Chemistry

The chemical data of groundwater samples are plotted in Gibbs diagram (Figure 3), representing TDS as a function of the ratio of cations [(Na+K)/(Na+K+Ca)] (Gibbs 1970). The Gibbs diagram, modified to suit this work, suggested equal processes of chemical weathering of rock-forming minerals and salinisation as a result of evaporation- crystallisation influencing the quality of groundwater which is circulating.

In Ghana, rock dissolution is apparently the dominant process influencing groundwater hydrochemistry in major hydrogeological terrains. Where silicate mineral weathering is the major controlling process, concentrations of the major physico-chemical parameters are relatively low. Wells completed within the weathered Dahomeyan gneisses in the area deliver relatively fresh groundwater whose quality is controlled by the weathering of silicate minerals. Groundwaters at Dagbamatey, Esusukofe, Dzuefe, Avenorfeme and Avenorfedo are dominated by the processes of mineral dissolution. This explains why these water sources produced the freshest water types in the area. On the other hand, samples from Fiato, Biase, Kpogedi, Afeyime and Health centre plotted within the "evaporation-crystallization dominance" field on grounds of high TDS and high Na/Ca+Na ratio. These wells are within tertiary arenaceous and argillaceous sediment. One cannot emphatically conclude that high salinities of these waters arose from saline seawater intrusion as alluded to by Yidana *et al* (2010) in the coastal Keta basin since the samples in this study are quite a distance from the Gulf of Guinea. Dissolution of evaporates and sea aerosol may best explain the hydrochemistry of these waters

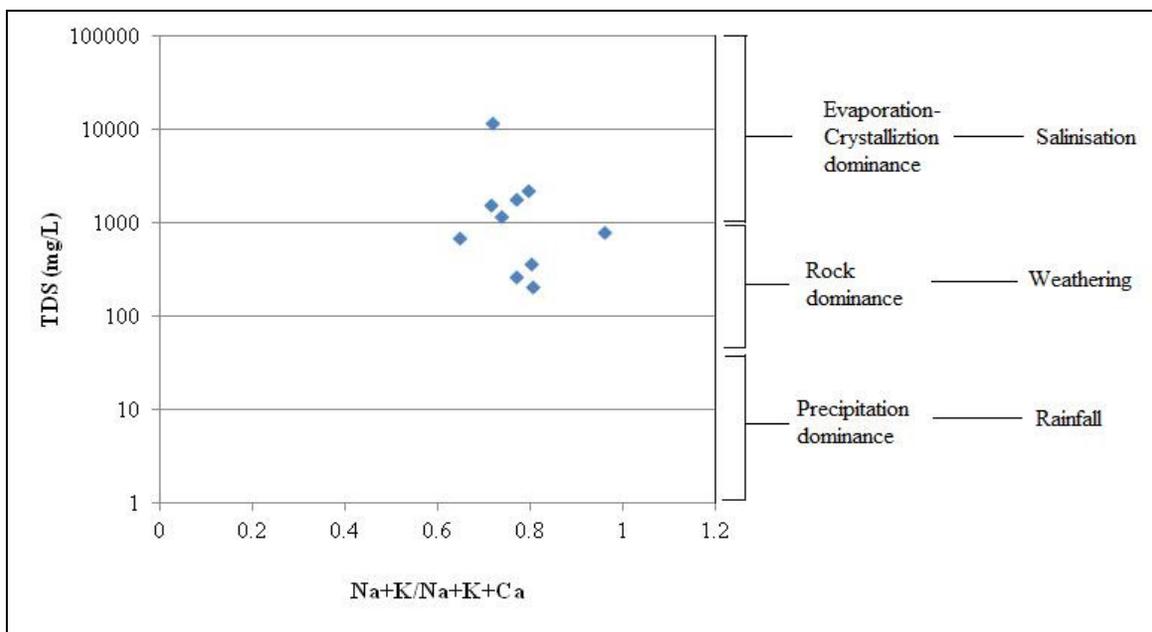


Figure 3: Gibbs variation diagram: TDS vs. (Na+K)/(Na+K+Ca).

It can be observed in Figure 4 (a plot of Cl^- against Na^+) that 90% of the samples plotted towards Cl^- on the 1:1 line pointing to the fact that mineral dissolution is not the only factor responsible for the quality of the groundwater in the area, especially, when Mg-Cl and Na- HCO_3 water types have been identified at Kpogedi and Avenorfeme respectively.

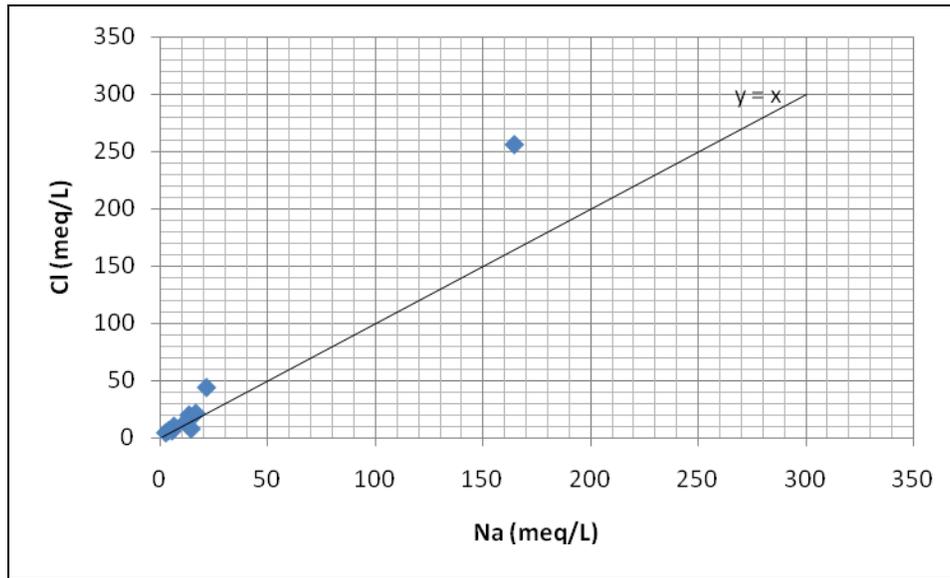


Figure 4: A plot of Cl^- against Na^+ (meq/L)

In order to investigate the occurrence of cation exchange reaction in the groundwater, $\text{Ca}^{2+} + \text{Mg}^{2+} - (\text{HCO}_3^- + \text{SO}_4^{2-})$ (meq) was plotted against $\text{Na}^+ + \text{K}^+ - \text{Cl}^-$ (meq/L) as in Figure 5. Since calcite and dolomite are the most likely additional sources of Ca^{2+} and Mg^{2+} to the groundwater apart from cation exchange, in plotting this diagram, possible contributions of Ca^{2+} and Mg^{2+} from calcite and dolomite dissolution to lithogenic Ca^{2+} and Mg^{2+} in the groundwater were accounted for by subtracting the equivalent concentrations of HCO_3^- and SO_4^{2-} (McLean and Jankowski, 2000).

Similarly, to account for lithogenic Na^+ available for exchange, it was assumed that Na^+ contribution from meteoric origin would be balanced by equivalent concentration of Cl^- and, therefore, equivalent Cl^- concentration was subtracted from that of $\text{Na} + \text{K}$ (Nkotagu, 1996; McLean and Jankowski, 2000). The samples clustered around a line of slope -1.5. Water undergoing ion exchange plots along a line with a slope of -1 in $\text{Ca}^{2+} + \text{Mg}^{2+} - (\text{HCO}_3^- + \text{SO}_4^{2-})$ plot field. Thus, suggesting in this case that ion exchange could be a significant process through which Na^+ partly enters the groundwater system.

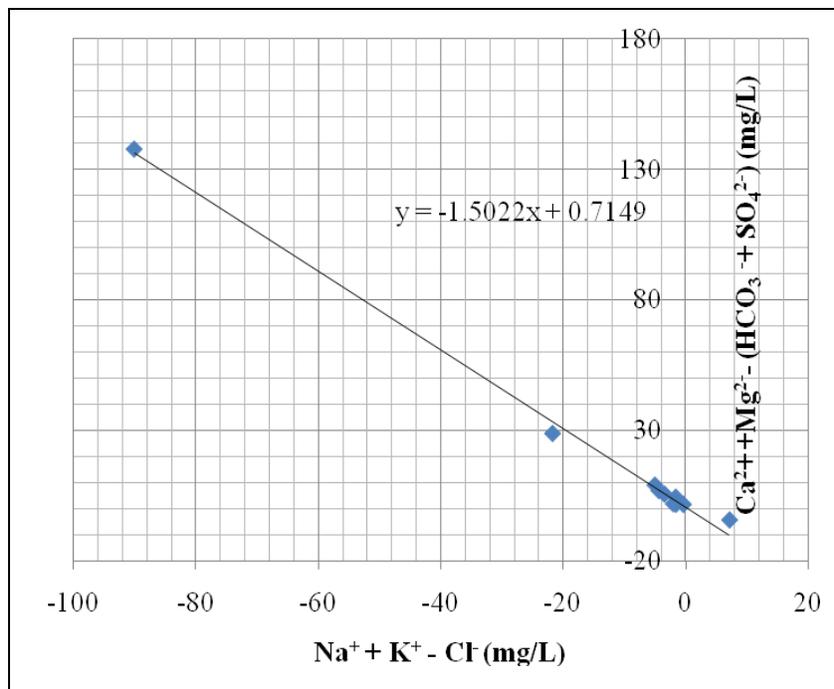


Figure 5: Bivariate plots of $\text{Ca}^{2+} + \text{Mg}^{2+} - (\text{HCO}_3^- + \text{SO}_4^{2-})$ versus $\text{Na}^+ + \text{K}^+ - \text{Cl}^-$

4.4. Suitability for Domestic Use

Water quality index (WQI) is a weighted summation of the composition of water, in which much weight is assigned to parameters which have critical health effects and whose presence above certain critical concentration limits could limit the usability of the resource for domestic purposes. The objectives are usually related to national as well as the World Health Organization's standards for each of the major parameters in drinking water. In this research, the objectives were based on the WHO (2003) standards for the major ions and chemical parameters as indicated in Table 3.

In calculating the WQI, 11 parameters were considered each of which was assigned a weight (w_i) in a scale of 1 to 5 according to its relative importance in the overall quality of water for drinking purposes (Table 4). Subsequently relative weight (W_i), quality rating scale (q_i) and sub-index (S_{ii}) - all with respect to the i th parameter, were calculated before eventually the WQI was calculated according to the formulae given below (Ramarkrishnaiah, 2009).

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i}$$

Where w_i is the weight of each parameter and n is the number of parameters. Calculated relative weight (W_i) values of all the parameters are also given in Table 4.

$$q_i = \frac{C_i}{S_i} * 100$$

Where C_i is the concentration of each chemical parameter in each water sample in mg/L, and S_i is the WHO, (2003) drinking water standard for each chemical parameter in mg/L.

$$S_{ii} = W_i * q_i$$

Where q_i is the rating based on the concentration of the i th parameter.

$$WQI = \sum S_{ii}$$

Analysis of water based on water quality indices leads to the classification of water into five types namely: "excellent", "good", "poor", "very poor" and "unsuitable for drinking" (Table 3). Accordingly, Dagbamatey, Dzuefe and Avenorfedo samples fell within the 'Excellent' category. The Biase and Avenorfeme water samples fell within the "Good" category. On the other hand, Fiato, Kpogedi, Afeyime and Esusukofe samples fell within the "Poor" category, while the Health centre water sample was in the "Unsuitable for drinking" category. All the samples within the Poor and Unsuitable for drinking categories had high sodium and chloride concentrations and were also associated with high EC values which translated into high TDS.

Water quality index (WQI)	Description
<50	Excellent
50-100	Good
100-200	Poor
200-300	Very poor
>300	Water unsuitable for drinking

Table 3: Water quality classification based on WQI value

Chemical parameters	Objectives to be met (mg/L) (WHO, 2003)	Weight (w_i)	Relative weight (W_i)
Na ⁺	200	3	0.073171
Ca ²⁺	200	3	0.073171
Mg ²⁺	150	3	0.073171
K ⁺	30	3	0.073171
pH	6.5	5	0.121951
TDS	500	5	0.121951
HCO ₃ ⁻	244	3	0.073171
NO ₃ ⁻	10	5	0.121951
F ⁻	1.5	5	0.121951
Cl ⁻	250	3	0.073171
SO ₄ ²⁻	400	3	0.073171
		$\Sigma w_i = 41$	$\Sigma W_i = 1$

Table 4: Relative weight of chemical parameters.

4.5. Total Hardness (TH)

Water hardness has no known adverse health effects; however, it causes more consumption of detergents at the time of cleaning (Schroeder, 1960). The Total Hardness (TH) was determined by the following equation (Hem, 1985):

$$TH = 2.497 [Ca^{2+}] + [4.115 Mg^{2+}]$$

where Ca^{2+} and Mg^{2+} concentrations are expressed in meq/L.

The classification of groundwater in the study area, based on hardness according to Sawyer and McCarty, (1967) is presented in Table 5. No sample collected fell under the soft class. Waters at Biase (313 mg/L), Esusukofe (400 mg/L), Afeyime (624 mg/L), Fiato (638 mg/L), Kpogedi (1738 mg/L), and Health centre (7600 mg/L) had their hardness above 300 mg/L and therefore referred to as very hard waters. The rest ranged from moderately hard (Dagbamatey (119mg/L) (Hem, 1985). Dzuefe (132 mg/L and Avenorfedo (144 mg/L) to hard Avenorfeme (160 mg/L) water. This means all the waters will not readily lather with soap. Magnesium and chloride ions are highly interrelated ($r^2 = 0.9687$) among themselves (Figure 6). This interrelationship indicates that the hardness of the water is permanent in nature.

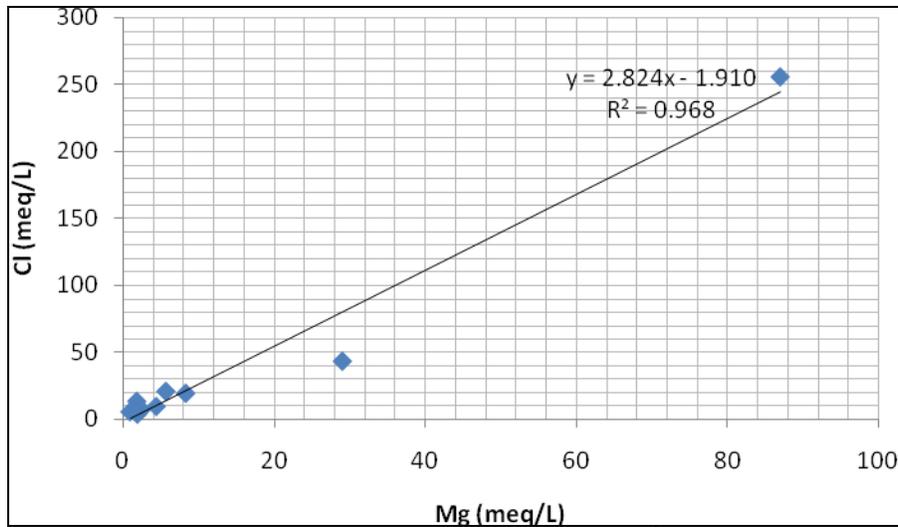


Figure 6: Binary plot of Cl against Mg^{2+} .

TH as $CaCO_3$ (mg/L)	Water class	Range (No. of samples)	%
<75	Soft	-	00
75–150	Moderately hard	119-144 (3 samples)	30
150–300	Hard	160 (1sample)	10
>300	Very hard	313-7600 (6 samples)	60

Table 5: Sawyer and McCarty’s classification for groundwater based on hardness

4.6. Suitability of Groundwater for Irrigation

The important chemical constituents that affect the suitability of water for irrigation includes salinity index or salinity hazard or total concentration of soluble/dissolved salt as determined on the basis of measured (EC) values; Sodicity index or sodium hazard or relative proportion of sodium to other principal cations as expressed by Sodium Adsorption Ratio (SAR); and chlorinity index (measured chloride ion concentrations in water) are discussed as follows:

4.6.1. Salinity Index/Salinity Hazard

The groundwater samples were placed under various categories according to the measured electrical conductivity values. According to the above classification, no sample collected was of excellent quality (Handa, 1969). In fact, a good number of the groundwater samples (50%) were above permissible quality, indicating that the waters are of poor quality. Groundwater at Health Centre (with EC 20500 μ S/cm) was the sample with the highest salinity. This water could be described as brine moderately concentrated per (Handa, 1969) classification.

EC/ $\mu\text{S/cm}$	Water salinity	Range (No. of sample)	%
00–250	Low (Excellent quality)	(0)	0
251–750	Medium (Good quality)	426-549 (2)	20
751–2250	High (Permissible quality)	752-1583 (3)	30
2251–6000	Very high	2355-4350 (4)	40
6001–10000	Extensively high	-	-
10001–20000	Brines weakly conc	-	-
20001–50000	Brines moderately conc.	20500 (1)	10
50001–100000	Brines highly conc.	-	-
>100000	Brines extremely highly conc.	-	-

Table 6: Classification of waters based on of EC (Handa, 1969)

Perhaps this resulted in dissolution of minerals as the water travelled through the lithology from recharge to discharge area. High salinity water is, however suitable for irrigating high salt tolerant crops. The water samples could also be classified into various salinity hazard categories based on their measured EC values (Table 7). Five samples were, according to the salinity hazard classification above, considered unsuitable for irrigation purposes. A more detailed analysis of the suitability of water for irrigation can be made by plotting sodium-absorption ratio and electrical conductivity data (Figure 7) on US Salinity Laboratory diagram (Richards, 1954). Accordingly, waters at Avenorfedo, Dzuefe and Dagbamatey fell in the category of the C2S1, indicating medium salinity/low sodium type. Samples at Esusukofe and Avenorfeme belong to the C3S1 and the C3S3 categories representing doubtful salinity/low sodium type and doubtful salinity/doubtful sodium type respectively. The rest four samples fell in the C4S2 category, meaning very high salinity/medium sodium type.

Salinity hazard class	EC ($\mu\text{S/cm}$)	Remark on quality	Range (No. of samples)
C1	100-250	Excellent	0
C2	250-750	Good	426-549 (2 samples)
C3	750-2250	Doubtful	752-1583 (3 samples)
C4 and C5	>2250	Unsuitable	2355-20500 (5 sample)

Table 7: Salinity hazard classes

Groundwater samples that fell in medium salinity hazard class (C2) can be used if a moderate amount of leaching occurs. High salinity/low sodium water (C4 and C5) can be suitable for plants with good salt tolerance, but can restrict its suitability for irrigation, especially in soils with restricted drainage (Mohan, 2000). High salinity water (C3, C4, and C5) cannot be used for irrigation of soils with restricted drainage. Even with adequate drainage, special management for salinity control is required and crops with good salt tolerance should be selected. Such areas need special attention as far as irrigation is concerned.

4.7. Chlorinity Index

Low salt tolerant crops are usually chloride sensitive (Ravikumar, 2010). The chlorinity index of the groundwater resources was calculated using the measured chloride ion concentrations in water. By this index, the groundwater samples were found to be suitable for irrigation except those at Health centre, Afeyime and Kpogedi which had chloride levels above 700mg/L.

4.7.1. Sodium Adsorption Ratio (SAR) or sodicity index

Sodium Adsorption Ratio (SAR) evaluates excess sodium or limited calcium and magnesium ions in water, otherwise known as sodium hazard (Karath, 1989). SAR is considered a better measure of sodium (alkali) hazard in irrigation water as it is directly related to the adsorption of sodium on soil and is a valuable criterion for determining the suitability of the water for irrigation. Excessive sodium contents relative to the calcium and magnesium reduce the soil permeability and thus inhibit the supply of water needed by crops. The SAR is used to predict the sodium hazard of high carbonate waters especially if they contain no residual alkali. It is computed as:

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}}, \text{ where all cationic concentrations are expressed in or meq/L.}$$

SAR value	Sodium hazard class	Remark on quality	Ranges (No. of samples)	%
<10	S1	Excellent	2.18-6.64 (8 samples)	80
10-18	S2	Good	11.31 (1 samples)	10
18-26	S3	Doubtful/Fairly poor	18.90 (1 samples)	10
>26	S4 and S5	Unsuitable	-	-

Table 8: Classification of waters based on SAR values and sodium hazard classes based on USSL classification (Richards, 1954).

The classification of groundwater samples from the study area with respect to SAR (Richards, 1954) is presented in Table 8. The SAR values of Biase, Esusukofe, Afeyime, Fiato, Kpogedi, Dzuefe, Avenorfedo, and Dagbamatey samples were found to be less than 10, and were classified as being excellent for irrigation (i.e., S1 category). The remaining samples from Avenorfeme and Health Centre were classified as good and doubtful respectively for irrigation.

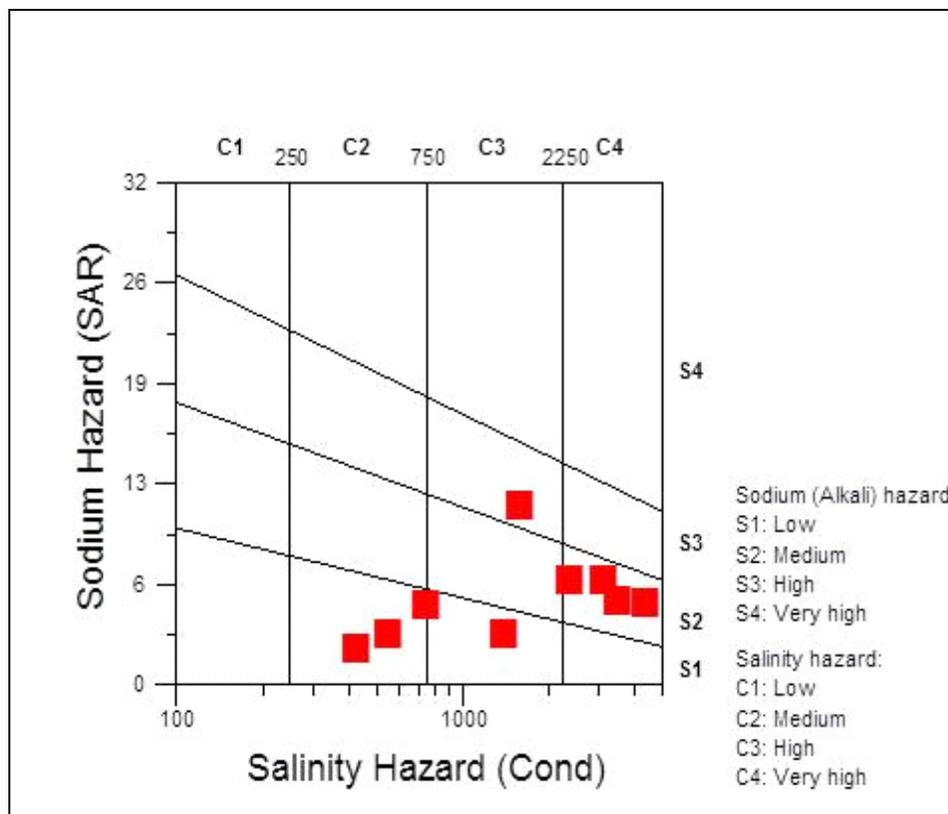


Figure 7: US salinity hazard diagram of water samples (after Richards, 1954).

5. Conclusion

Groundwater in the Avenorfeme and its environs has been assessed for its quality for use for both domestic and irrigation purposes. On the basis of the WQI as computed, groundwater in Dagbamatey, Dzuefe and Avenorfedo fell within the 'Excellent' category. The waters at Biase and Avenorfeme fell within "Good" category. Fiato, Kpogedi, Afeyime and Esusukofe fell within "Poor" category, whilst water at Health centre was in the "unsuitable for drinking" category. The groundwater in the study area can be classified under moderately hard (Avenorfedo, Dagbamatey and Dzuefe), hard (Avenorfeme) and very hard (Afeyime, Biase, Esusukofe, Fiato and Health Centre) categories based on hardness. The suitability of groundwater for irrigation was also evaluated based on the irrigation quality parameters such as Salinity index/ sodium hazard, Sodium Adsorption Ratio (SAR), and Chlorinity index. Majority of the samples fell in categories ranging from excellent to suitable for irrigation according to all the above indices except salinity hazard. The samples which are not suitable for irrigation based on the irrigation quality parameters may be suitable for irrigation in well-drained soils. Analysis of the hydrochemical parameters suggested the groundwater quality could be largely attributed to the weathering of silicate and accessory minerals. It was evident from the higher values for physico-chemical parameters like hardness, TDS, chloride and sodium that most of the groundwater samples analyzed in the present investigation might have had natural influences. The water types that predominated in the study area were Na-Cl type (80%), followed by Mg-Cl (10%) and Na-HCO₃ (10%) types.

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