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Groundwater Quality and Hydrogeochemistry of Toungo Area, Adamawa State, North Eastern Nigeria

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Abstract Analytical results revealed that the water from various sources in the study area is unfit for human consumption due to bacteriological pollution. The water quality for agricultural practice indicated that water is good for agricultural practice. The Sodium Absorption Ratio (SAR) values range from 0.04 meq/l to 0.60 meq/l with an average of 0.13 meq/l. The Residual Sodium Carbonate (RSC) values range from 0.35 meq/l to 2.64 meq/l with an average of 1.43 meq/l as to of the water of generally safe. Total dissolved solid (TDS) values ranges from 95 to 285 mg/l hence the water is good for irrigational purposes. The study also revealed that the water may be unsuitable for some industries due to high iron concentration in some places, the values range from 0.21 to 3.97 mg/l with an average of 0.5 mg/l which indicate values above the recommended limits of 0.2 mg/l for industrial purpose. The water has total hardness ranging from 19.64 mg/l to 92.01 mg/l with a mean value of 50.97 mg/l, hence suitable for some industrial activities. PCA, HCA and rock-water interaction diagrams identified diffused form of contamination, leaching of bed rock geochemistry, salinity, natural mineralization, anthropogenic contamination, silicate weathering and oxidation as the major processes controlling the groundwater geochemistry. The groundwater is of calcium magnesium bicarbonate facies which belong to the normal alkaline group.

Keywords: *bacteriological pollution, agricultural practice, water quality, groundwater, industries, geochemistry*

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1. Introduction

The study area forms part of the Yola arm of the Upper Benue Trough North eastern Nigeria. The people living in this area are mostly farmers and cattle rearers. The area is inhibited by the Fulani who are traditionally livestock rearers of Northern Nigeria and the Chamba people who cultivate crops like millet, beans groundnut, maize, cassava and guinea corn.

In any hydrogeological setting surface water and groundwater are the main sources of water supply. Surface water in the area includes; water from River Kom, streams, and lakes, whereas groundwater is obtained from boreholes, hand-dug wells and springs. Both sources of water are prone to contamination and pollution. Hence, the need for water quality assessment for enhanced socio-economic growth and development [14].

Evaluation of water quality for human consumption, agricultural and industrial activities have not been given attention especially in developing countries like Nigeria. The chemical composition of water is an important factor to be considered before it is used for domestic or irrigation purpose [36]. Water is the primary need of every living thing on this planet earth which is essential for sustaining life. Hence, the need for the analysis of water hydrogeochemically and bacteriologically in other to know the acceptable quality for various purposes which must be pursued. Groundwater is never chemically pure, dissolution of substance takes place in the course of its percolation through the rocks and groundwater which makes itacquire some of these dissolved chemical constituents.

The chemical composition of groundwater is important if the water is to be used for domestic, industrial and agricultural purpose. The dissolved geochemical constituents in water affect its usage for various purposes. The concentrations of the dissolved constituents are correlated with the standards of the World Health Organization (WHO) or other organizations charged with the responsibility of providing safe drinking water to the ever increasing population.

No work has been done precisely on the study area. Most of the previous works in the area are mainly regional in nature. The geological survey of Nigeria initiated the search for water as far back as 1926 by carrying out the hydrogeological investigations in parts of Northern Nigeria. This led to the exploitation of groundwater through hand-dug wells and boreholes. By 1938, a water well drilling section was set up in the geological survey of Nigeria.

Carter et al. [7], Du Preeze and Barber [11] and Consulting Nigerian Limited [8], respectively published some details about the geology, hydrogeology and water quality of some parts of the then northern Nigeria.

Another work was also done by Kiser [17] which involved detailed chemical analysis of groundwater in Northern Nigeria. Furthermore, the government of Northeastern States under the Ministry of Works and Housing carried out physical and chemical analysis of water in 1975.The work by Ntekim [25] reveals that the chemical characters of groundwater in Adamawa State are meteoric and has been influence by bedrock chemistry as well as atmospheric and environmental activities.

The work by Ishaku et al. [16], assessed water quality for enhanced rural water supply in Adamawa State Northeastern Nigeria. Similar work was done at Michael Opara University of Agriculture Umudike and Environs Southeastern Nigeria by Magnus [20]. Subsequently, Magnus [20] carried out hydro chemical evaluation of groundwater in the Blue Nile Basin, Eastern Sudan, using conventional and multivariate techniques.

This research work is aimed at evaluating the quality groundwater from hand-dug wells and boreholes in Toungo area thereby ascertaining the suitability of the water for domestic, agricultural and industrial activities. The study is alsoaimed at assessing the geochemical processes affecting the groundwater chemistry.

1.1. The Study Area

The study area is Toungo town; it constitutes part of sheet 238 Toungo S.W on a scale of 1:50,000. It lies within latitudes 08° 05′ N to 08° 09′ N and longitudes 12° 03′ E and 12° 06′ E, and covers an area of about 57.7 km^2 (Figure 1). The area form part of Yola Arm of the Upper Benue trough.

The area is characterized by moderate to high relief; it is mark by isolated hills and valley, and towards the central part there are few hills which stand out with the general elevation, with boulders and minor hills surrounding it. The elevation rises from 1,400 to 1,750 m above mean sea level; the area is well drain by ephemeral rivers and streams which gather most of the runoff from the hills. The drainage system exhibits a dentritic drainage pattern and it is dominated by the River Kom which flows from northeast to southwest (Figure 1).

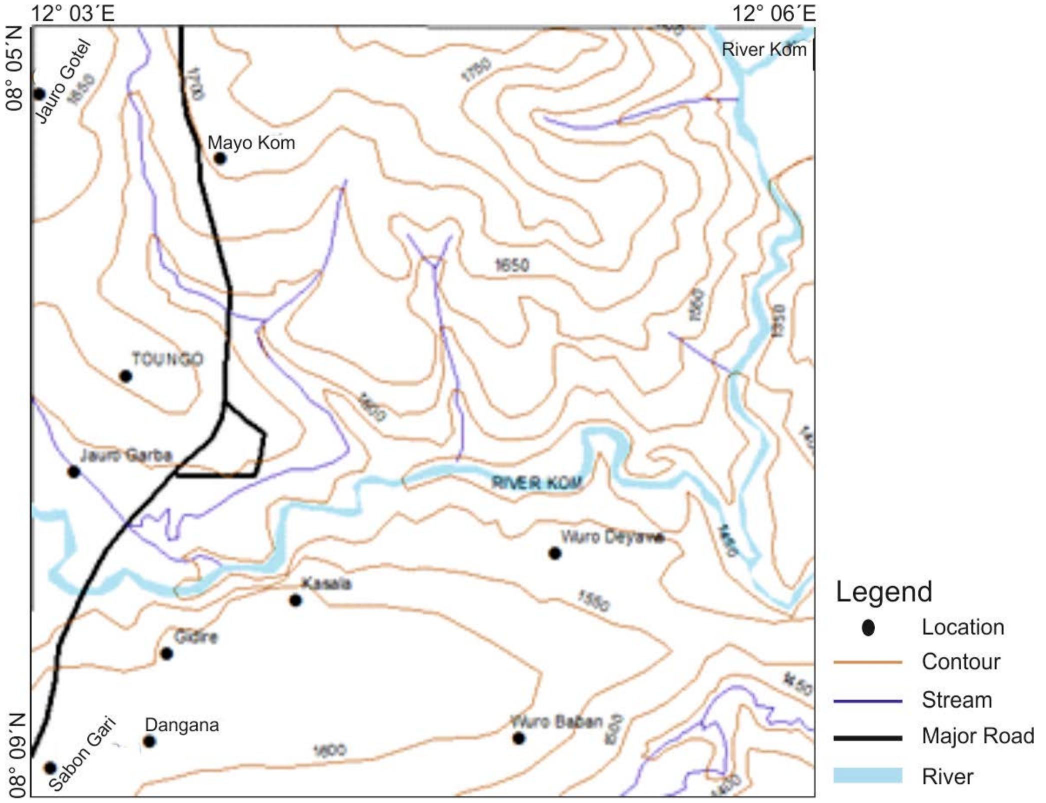

Figure 1. Topographic map of the study area

The study area is mark by two distinct seasons: the rainy season which start from April to October and the dry season which starts from November to March [38]. The annual rainfall and its variation were based on data recorded from existing rainfall gauging station at Upper Benue River Basin Authority Yola. The mean annual rainfall is about 700 to 1,200 mm. The rainfall begins in March and ends in November, with July, August and September recording the heaviest rainfall. The mean annual temperature range from 24 to 27°C with an average of 26°C recorded during the dry season. In the area humidity is generally low during harmattan period (December to January) due to the onset of the northeast trade wind from the continental interior. The increase in humidity is noted during rainy season from April to October.

1.2. Geology and Hydrogeology of the Study Area

The study area is underlain by the Pan African granites which occupy about two third of the study area, and enclosed the migmatite – gneiss – quartzite complex. They are mostly located to the east and north central portion of the area. The granites have been identified as biotite granite, pegmatitic granites, granite gneisses and amphibolite (Figure 2). According to Rahaman [31], the older granites were emplaced during the Pan African thermotectonic event (450 ma).

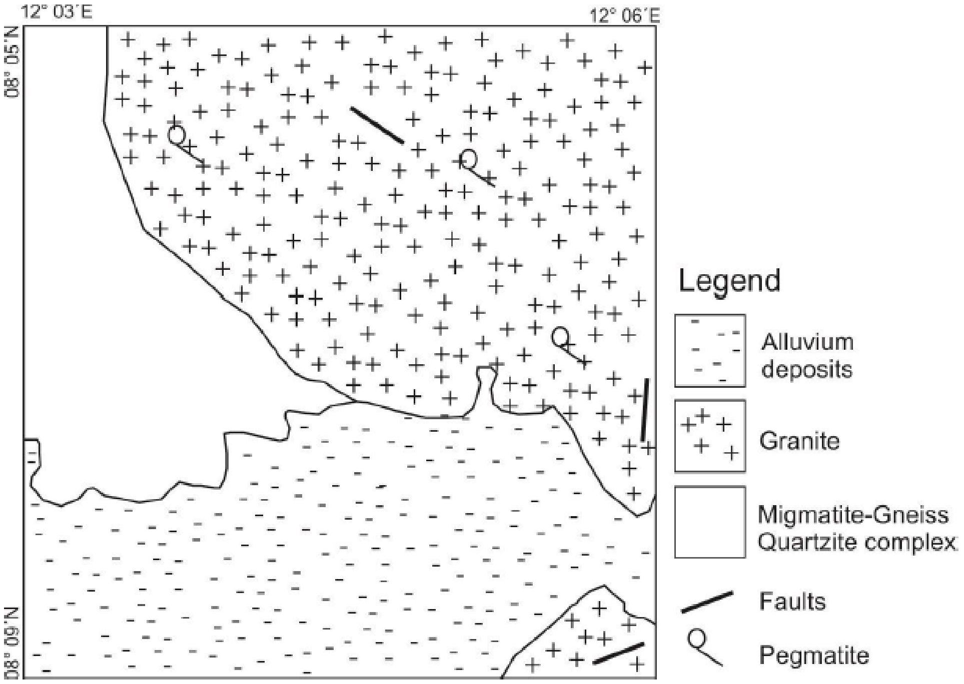

Figure 2. Geological map of the study area

The youngest deposits in the area include eluvium and the alluvial deposit. The eluvium is the weathered portion of the Precambrian basement and is mostly lateritic located in south-east and western portion of the study area, while the alluvial is characterized by sands, silts, clays and gravels and arefound along floodplains in the area.

Figure 3 indicates that groundwater flow takes place from mayo Kom in the north and flows towards the northeast and north west, respectively. Another flow zone takes place from Wuro Baban in the south and flows towards Wuro Deyawa in the south east and also flows towards Kasala. Groundwater flow also takes place from Sabon Gari in the south and flows towards the southwest. Recharge areas occur around Wuro Baban in the south, mayo Kom in the north and Sabon Gari area. Discharge areas occur around Wuro Deyawa, Jauro Garba and Jauro Gotel areas, respectively.

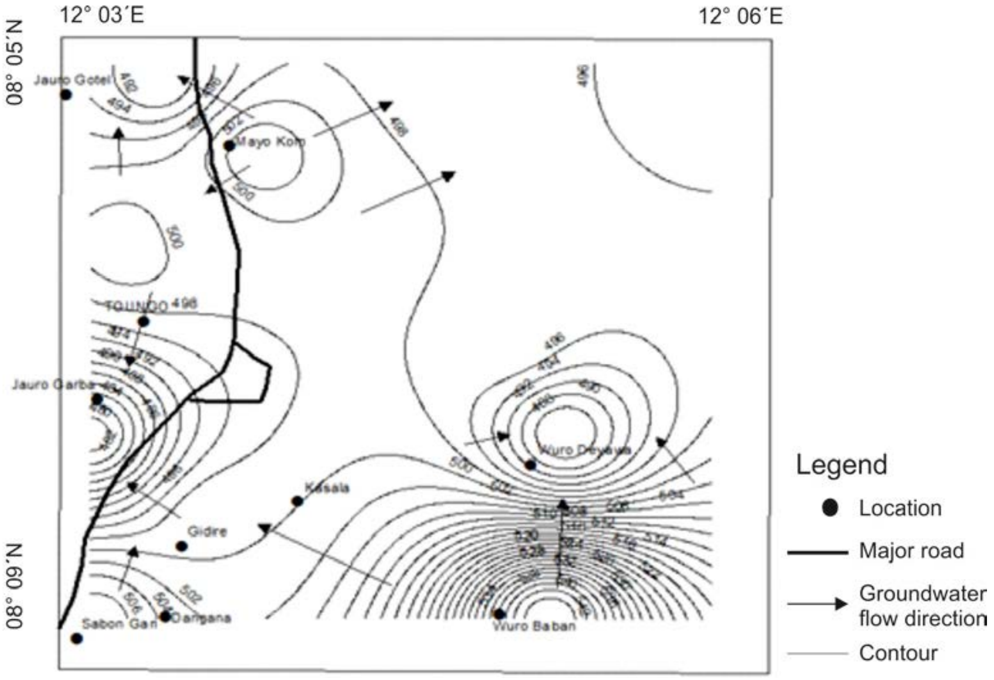

Figure 3. Hydraulic head distribution in unconfined aquifer in the study area

The boreholes in the study area generally attain average depth of 30 to 45 m tapping water largely from the unconfined aquifers. The weathered overburden aquifer generally has a thickness of about 9 m while the fracture basement aquifer is about 20 m thick (Figure 4). The water level is generally 4 m from ground surface and shallow wells yield is about 200 to 1,000 litres per minute in the study area. The hand-dug wells generally have depth of about 3 to 8 m at most locations [38].

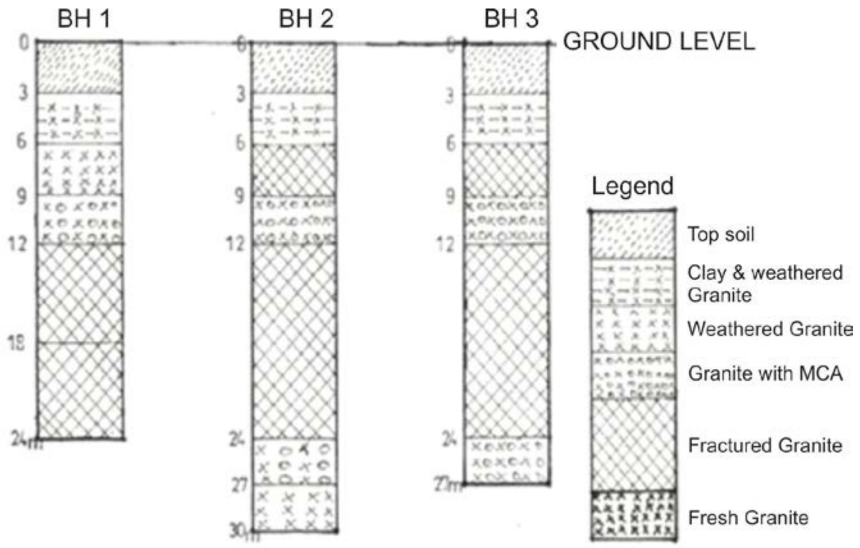

Figure 4. Lithologic log of some boreholes in the study area

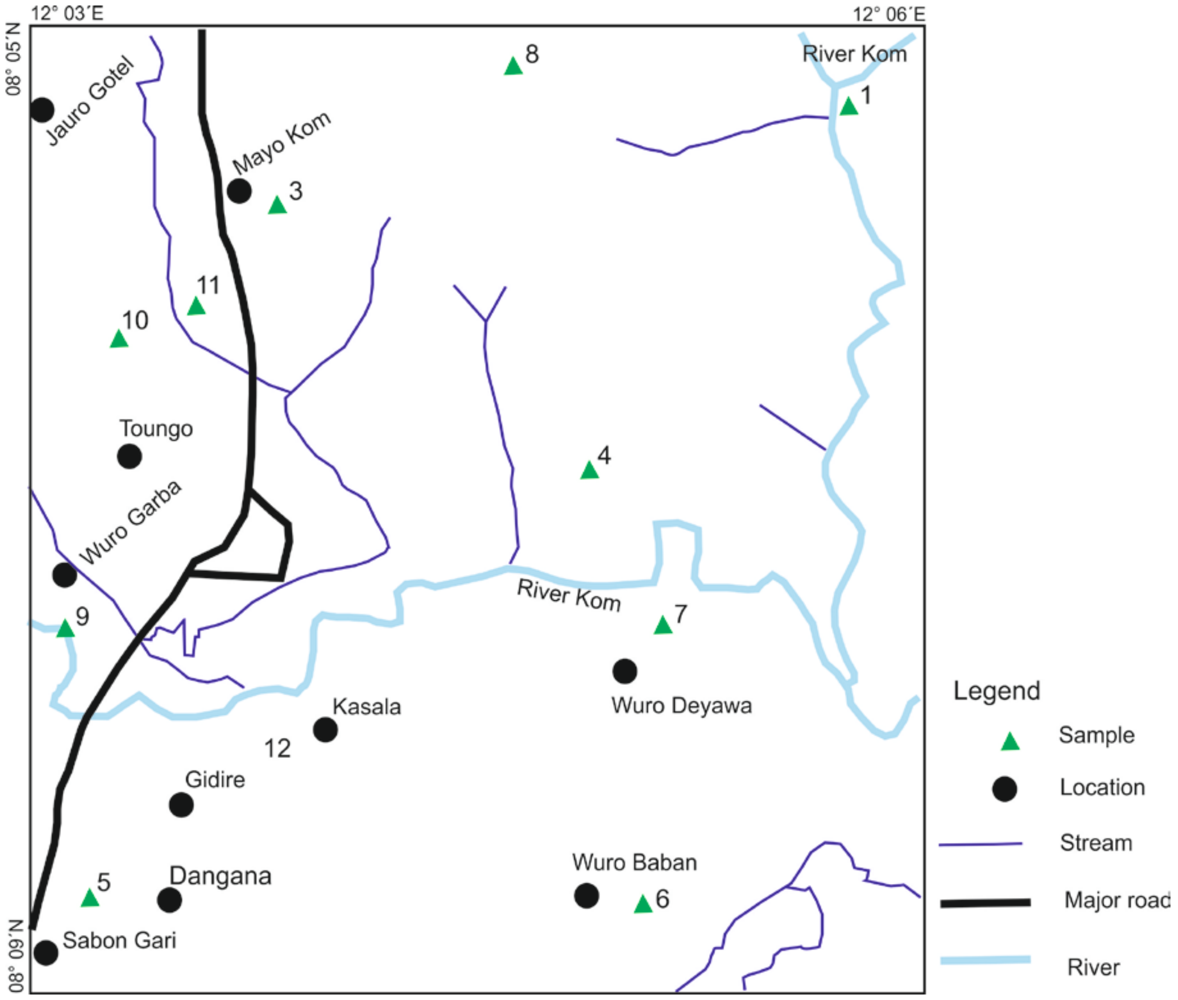

Figure 5. Sampling points in the study area

2. Methodology

The first of this work stage involved the collection of topographic map from Adamawa State Land and Survey (Figure 1). The second stage involved the collection of ten water samples from boreholes and hand-dug wells (Figure 5). The field work took place on 28th August 2012. The position of boreholes and hand-dug wells were determined using the Global Positioning System (GPS) and later transferred to the base map of the study area. Before collection, the water samples were collected in one-litre containers which were rinsed thoroughly with the water to be sampled according to Bercelona et al. [5]. Physical parameters such as temperature, pH, conductivity and total dissolved solid (TDS) were measured in the field using

TDS/conductivity meter (HACK KIT), while pH was measured using a portable pH meter. The chemical analysis was carried out using HACH digital spectrophotometer (model DR 2400), and samples were also analysed bacteriologically using the membrane filtration method according to WHO. The entire sample for chemical analysis was carried out within 24 hours of collection. While samples for bacteriological analysis was carried out within same period of time. The analysis was carried out at the Adamawa State Water Board Yola. The results were then subjected to statistical analysis using SPSS software version 15.0 and presented in for of minimum, maximum, mean and standard deviation. The geochemical processes were studied using the rock-water interaction diagrams.

The advanced multivariate statistical analysis techniques were adopted in this study using the Statistical software SPSS statistics, version 15.0. Multivariate analyses were employed because of its usefulness as a tool to reduce and organize large hydrochemical data sets into groups with similar characteristics and then relating them to specific changes in hydrological processes [28]. The multivariate statistical analyses such as PCA and Hierarchical Cluster Analysis (HCA) have been used to provide a quantitative measure of relatedness of water quality parameters and to suggest the underlying natural and anthropogenic processes in groundwater aquifers [22].

The Principal Component Analysis (PCA) is a multivariate statistical analysis for the purpose of data reduction with a view to determining the sources of elements and their controlling factors [15]. In PCA many factors can be obtained as there are many parameters/variables in the data set [24]. The total number of factors generated from a typical factor analysis indicates the total number of possible sources of variation in the data [4]. The multivariate statistical technique therefore relates variables into principal associations (factors) based on their mutual correlation coefficients and these associations may be interpreted in terms of mineralization, lithology and environmental processes [26]. Suleiman and Sameer [35], classify factor loadings into ‘strong’, ‘moderate’ and ‘weak’ corresponding to greater than 0.75, 0.75-0.50 and 0.50-0.30, respectively. Significant attention is given to variables with strong positive or negative contribution to the factorial axis which is easier to understand the source of variability explained by the factor [24].

The Hierarchical Cluster Analysis (HCA) groups objects into classes or clusters on the basis of similarities within a class and dissimilarities [33]. A low distance shows the two objects are similar or close together whereas a large distance indicates dissimilarity [3]. The HCA according to Ward [40] with squared Euclidean distances was applied to detect multivariate similarities in groundwater quality. The results are presented as dendrogram of the groups and their proximity [27].

3. Results and Discussions

The standard for drinking water is based on two main criteria: the presence of objectionable taste, odours and colours and the presence of substances with adverse health effects [9]. The dissolved geochemical constituents in groundwater (Table 1) are correlated with the World Health Organization (WHO) standards (Table 2). Hydro geochemicalresults which are considered in the evaluation of water quality for domestic purposes reveal that the physical properties pH, EC and temperature are generally below the recommended limit of WHO [41,43]. The pH values range from 4.2 to 6.2 with an average of 5.3, which indicates the acidic condition of the water. TheElectrical Conductivity (EC) of the water samples range from 141 µS/cm to 424 µS/cm with a mean value of 244.7µS/cm which indicate low and fall within the recommended WHO [43] standards of 500 µS/cm. The temperature values range from 16.7°C to 21.7°C which fall below the recommended values of 30°C to 35°C of WHO [41]. The TDS values range from 95 mg/l to 285 mg/l, the values are within the recommended limit of WHO [43].

Table 1. Chemical and bacteriological results of analysis from the different water sources in the study area

Sample location	Temp. (°C)	pH	Cond. (µs/cm)	TDS	HCO$_3$ (mg/l)	CO$_2$ (mg/l)	Total hardness (mg/l)	Fe^{2+} (mg/l)	F (mg/l)	Cl$^-$ (mg/l)	NO$_3$ (mg/l)	Mg^{2+} (mg/l)	Na$^+$ (mg/l)	Ca$^+$ (mg/l)	SO$_4$ (mg/l)	K$^+$ (mg/l)	Cu^{2+} (mg/l)	colifm count cfu/ml	RCS	SAR
BH1	19.80	4.6	162	110	171	0.00	52.93	0	0.25	10.31	12.11	28.47	1.02	30.18	21.39	2.06	ND	7	0.87	0.04
BH2	21.70	5.4	198	130	174	0.00	23.03	0.11	0.04	49.77	43.38	14.52	0.14	10.91	23.26	1.1	0.01	76	1.92	0.00
BH3	19.67	6.2	319	210	217	0.00	58.88	0.02	0.17	11.11	19.23	27.43	0.09	31.06	14.93	3	0	10	1.62	0.00
BH4	21.00	6	221	150	236	0.00	92.01	3.97	0.012	87.68	68.1	45	6.41	48.91	27.63	7.61	ND	4	0.77	0.22
BH5	20.37	5.3	159	105	211	0.00	21.93	0.17	0.19	15.73	37.86	11.96	0.18	13.03	27.33	3.96	0	16	2.64	0.00
BH6	18.62	4.3	247	163	153	0.00	63.61	0	0.11	9.26	10.16	30.22	0.94	36.17	16.56	2.1	ND	13	0.35	0.04
HDW1	18.00	4.2	424	285	131	2.00	79.74	0.43	0.06	23.83	54	14.61	2.96	19.27	29.39	4.4	ND	19	1.12	0.02
HDW2	19.73	5.1	269	177	193	3.10	50.42	0.016	0.41	10.88	8.19	27.21	1.76	21.96	22.18	2.4	0.06	26	1.59	0.08
HDW3	16.73	5.9	141	95	198	0.00	43.28	0.03	0.31	7.77	26.39	24.62	2.08	21.33	18.62	1.7	ND	28	1.61	0.10
HDW4	21.00	5.7	307	201	168	1.70	30.12	0.09	0.09	16.91	14.67	15.88	3.61	17.21	16.97	3.31	0	40	1.74	0.20

BH=Borehole, HW=Hand-dugwel.

The evaluation of water quality revealed that parameters such as magnesium, sulphate, chloride, and total hardness are generally low. Magnesium concentration varies from 12 to 45 mg/l and falls within the recommended limit of WHO [43]. Sulphate varies from 14.9 to 29.4 mg/l with mean value of 21.8 mg/l, which is within the recommended limit of 400 mg/l of WHO [43]. Nitrate concentration values range from 8.2 mg/l to 68.1 mg/l with mean value of 29.4 mg/l. About 30% of the water samples indicate values above WHO [42] recommended limit of 50 mg/l. High nitrate concentration is responsible for the blue baby syndrome (methamoglobiemia). The northeastern and northwestern parts of the study area show high nitrate values above WHO standards (Figure 6), these areas are therefore characterized by high risk of nitrate contamination.

Table 2. Summary of groundwater quality in the study area

Parameters	Minimum	Maximum	Mean	Standard Deviation	WHO (2011)
Temperature (°C)	16.70	21.70	19.66		30 – 35*
pH	4.20	6.20	5.27	0.712	6.5 - 8.5
EC (µS/cm)	141.00	424.00	244.7	88.08	500
TDS (mg/l)	95.00	285.00	162.600	58.487	500
Sodium (mg/l)	0.10	3.60	1.322	1.256	200
Potassium (mg/l)	1.70	7.60	3.25	1.778	12
Magnesium (mg/l)	12.00	45.00	23.99	10.0558	50
Calcium (mg/l)	10.90	48.90	25.01	11.642	75
Bicarbonate (mg/l)	131.00	236.00	185.20	31.762	500
Chloride (mg/l)	7.80	87.70	25.23	25.623	250
Sulphate (mg/l)	14.90	29.40	21.83	5.079	250
Nitrate (mg/l)	8.20	68.10	29.42	20.596	50**
Fluoride (mg/l)	0.01	0.40	0.175	0.12713	1.5
TH (mg/l)	21.90	92.00	51.58	23.222	500**
Iron (mg/l)	0.00	4.00	0.486	1.241	0.3
Copper (mg/l)	0.00	0.06	0.0167	0.02422	1.5
Coliform	4.00	122.00	37.0000	37.08957	0 - 3

* World Health Organization [41], **World Health Organization [42].

Iron concentration from the water samples range from 0 to 0.4 mg/l, these values are within the recommended limit of 0.3 mg/l of WHO [43]. The high iron concentration in BH4 of 4.0 mg/l, exceeded the recommended limit of WHO. Fluoride concentration ranges from 0.01 to 0.4 mg/l with an average of 0.22 mg/l which is below the recommended limit of WHO [43] The bacteriological analysis reveals high coliform number count ranging from 4 to 122 which indicate bacteriologically contaminated water. Bacteriological contaminated groundwater is associated with water borne diseases such as viral hepatitis, schistosomiasis and cholera. The quality of groundwater in some section of the study area is bacteriologically contaminated and therefore unfit for human consumption. Pockets of areas containing lessthan 10 coliform counts occur in the western and northern part of the study area (Figure 7).

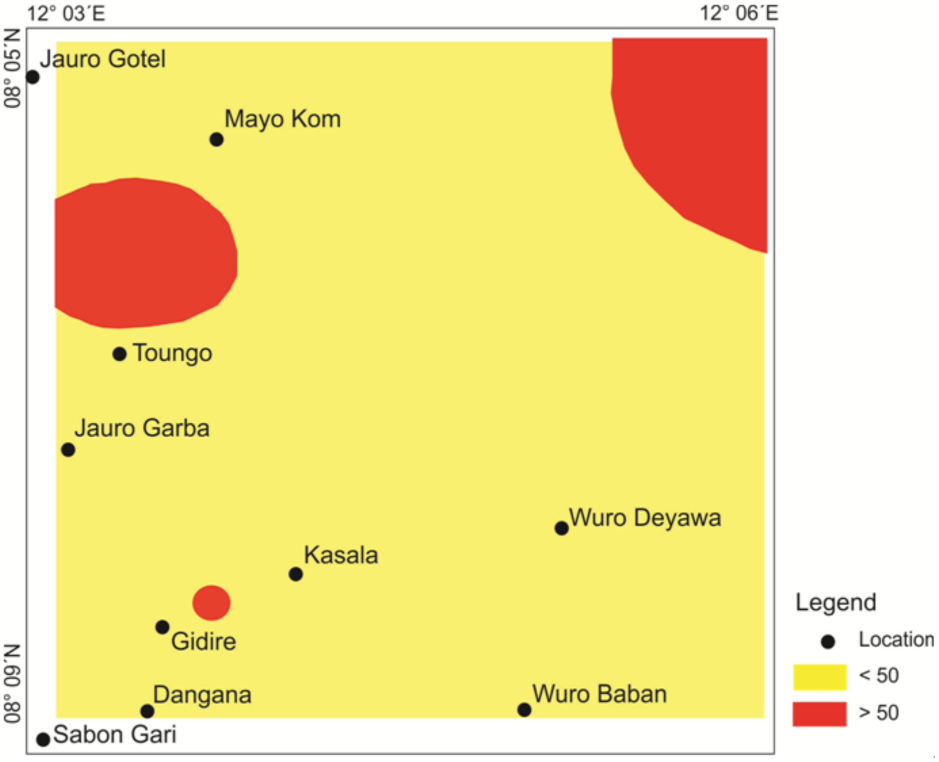

Figure 6. Spatial distribution of Nitrate in the study area

The electrical conductivity (EC) is a good measure of salinity hazard to crops, excess salinity reduces the osmotic activity of plant and thus interferes with the absorption of water and nutrients from the soil [32]. The EC values ranged from 141 to 424 µS/cm with mean value of 244.7 µS/cm. The EC values are within the range of excellent to good quality water for irrigation practice [39]. The values of TDS from the water samples range from 95 to 285 mg/l with mean value of 162.6 mg/l, all the values are less than 1000 mg/l, hence are within the non-saline class. The computed SAR values for all the water samples vary from 0.04 meq/l to 0.60 meq/l with an average of 0.40 meq/l. The results of analysis are correlated with the standard SAR values. The water samples from the study area can be utilized on all agricultural soil [21]. All the values are within the excellent class and can be applicable on all soils.

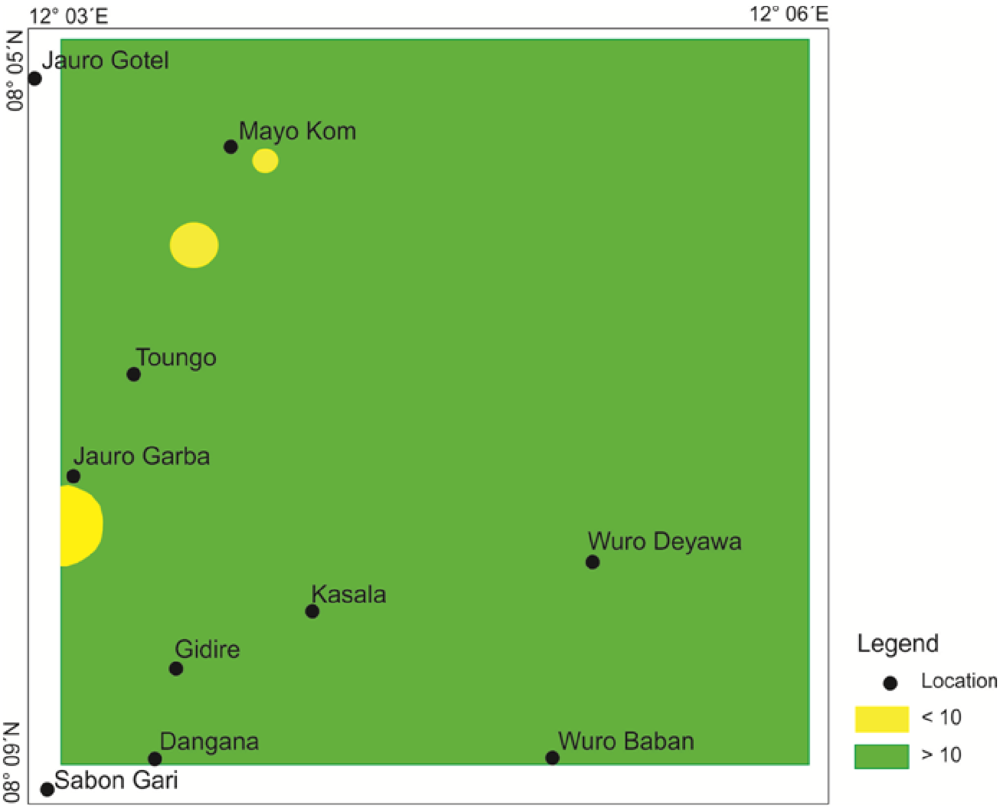

Figure 7. Coliform distribution in the study area

According to the California Fertilizer Committee [6], the Residual Sodium Carbonate (RSC) of less than zero is the most desirable for irrigational purposes, an RSC ranging from 0 to 1.24 mg/l is probably safe, RSC ranging from 1.25 to 2.50 mg/l is high and therefore suggest that water with such RSC should only be used on appropriate soil. The RSC values of the samples vary from 0.30 meq/l to 2.64 meq/l with an average of 1.43 meq/l, from the result in Table 2, 95% of the water is generally safe for irrigational practices, while the remaining 5% of the sample have potentials to cause salinity problems, hence if used on soil, it may likely develop salinity problem.

According to Okafor [29] water for industrial use should be odourless, colourless, free from suspended matter and micro-organism and should be of low iron and manganese contents. Water used in boilers should be soft and non-corrosive, while laundry water should be soft and colourless. Iron and manganese concentration above 0.2 mg/l precipitate upon oxidation and causes stain on plumbing features and foster growth in reservoir filters and distribution system [37]. Most industrial users object to water containing more than 0.2 mg/l of iron and manganese. From the results presented in Table 1, the iron concentration range from 0.00 mg/l to 4 mg/l, with an average of 0.5 mg/l. Based on the above standard 98% of the water samples reveal low concentration of iron except in BH4 which reveal value of 3.97 mg/l. The values of total hardness range from 21.9 to 92 mg/l with an average of 51.6 mg/l. From the hardness classification of water after Vasanthavigar [39], only water samples from HDW1and BH4 arecharacterized by hard water. All the other water samples have total hardness <75 hence are classified as soft water, so the water is suitable for industrial usage.

Table 3. Rotation Principal Component Analysis (PCA) loading matrix

Elements	Component		
	1	2	3
Temperature	0.514	-0.225	-0.396
pH	0.120	0.127	-0.627
EC	0.198	0121	**0.846**
TDS	0.212	0.139	**0.853**
Bicarbonate	0.158	0.344	-0.800
TH	0.252	**0.873**	0.369
Iron	0.699	0.639	-0.250
Fluoride	-0.744	-0.047	-0.119
Chloride	**0.884**	0.319	-0.180
Nitrate	**0.912**	0.129	-0.026
Magnesium	-0.002	**0.932**	-0.289
Sodium	-0.142	-0.124	**0.684**
Calcium	0.071	**0.958**	-0.124
Sulphate	**0.750**	-0.084	0.107
Potassium	**0.793**	0.489	-0.020
% Variance explained	28.83	23.72	23.06
% Cumulative	28.83	52.55	75.61

Multivariate Statistical Analyses

Principal Component Analysis (PCA) on chemical data indicates three factors which explain about 75.61% of the total variance (Table 3). Factor 1 accounts for about 28.83% of total variance and is characterized by strong positive loading with respect to NO_3^-, Cl^-, K^+ and SO_4^{2-}. Factor 1 is interpreted as diffused form of contamination due to application of chemical fertilizer such as NPK, potash and manure [15]. Factor 2 accounts for about 23.72% of the total variance, and exhibits strong positive loadings with respect to TH, Ca^{2+} and Mg^{2+}. The association of these elements to this factor may be attributed to leaching of bed rock materials, weathering and rock-water interaction. Hardness of water is caused by calcium and magnesium ions and can be tied to bed rock geochemistry [30]. Factor 3 accounts for about23.06% of the total variance, and has strong positive loadings with respect to EC, TDS and moderate loading with respect to Na^+. This factor accounts for the temporary salinity of the water. The presence of Na^+ may be due to cation exchange by which Ca^{2+} and Mg^{2+} are replaced by Na^+ [28].

The results of cluster analysis are presented in Figure 8 and indicate two clusters. Cluster 1 is subdivided into two sub clusters, and sub cluster 1 comprises of EC, TDS and Na^+. This sub cluster is also related to factor 3. The sub cluster 1 is interpreted as salinity controlled by Na^+. The second sub cluster comprises of pH, and temperature with fluoride loosely bounded to the cluster. This cluster is ascribed to natural mineralization involving fluorite. Cluster 2 is also subdivided into two sub clusters; the first sub cluster shows close similarities between Ca^{2+}, Mg^{2+} and TH, and second sub cluster shows close similarities between Fe^{2+}, K^+, NO_3^-, Cl^- and $SO_4^{2}$and is interpreted as anthropogenic contamination.The first sub cluster is related to factor 1and controls the hardness of the water.

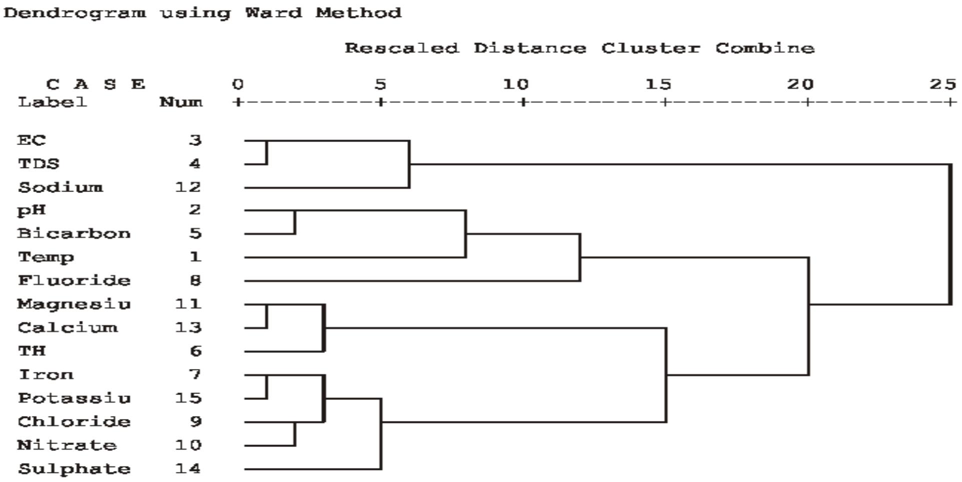

Figure 8. Dendrogram of hydrochemical data

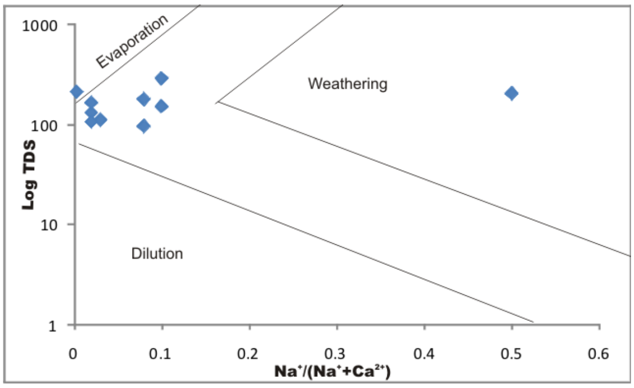

Figure 9. Plotting in Gibbs Diagram for Cations

Rock-water Interaction

The concentration of dissolved ions in groundwater depends on the hydrogeochemical processes that take place in the aquifer [23]. The authors added that the study of relative concentrations of the various major ions in groundwater is used in the identification of geochemical processes. Generally, different chemical processes occur during rock-water interaction, which include dissolution/precipitation, ion exchange processes, oxidation and reduction. The mechanisms controlling groundwater chemistry can be interpreted by Gibb's scatter diagrams and Piper diagrams and [23]. The plots of $Na^+/(Na^++HCO_3^-\ Ca^{2+})$and $Cl^-/(Cl^-+HCO_3^-)$ as a function of TDS are widely employed to determine the sources of dissolved geochemical constituents. Gibbs [13] indicated a close relationship between water composition and the hydrochemical processes involving precipitation, water interaction and evaporation. Figure 9 and Figure 10 indicate that most points of the samples plotted in the region of rock dominance and weathering.

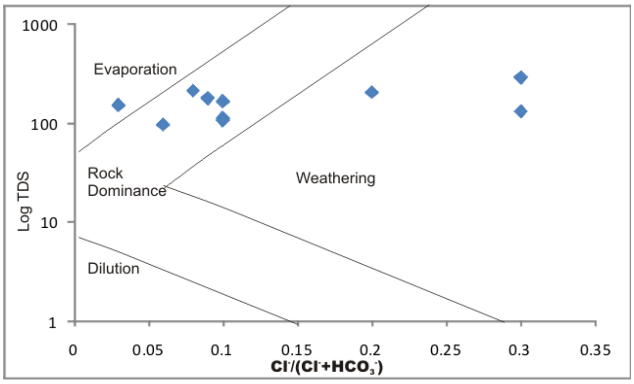

Figure 10. Plotting in Gibbs Diagram for Anions

Calcium and Magnesium

In the scatter diagram (Figure 11), about 70% of the samples plotted above the 1:1 equiline, thus representing carbonate weathering. Carbonate weathering may be caused by atmospheric water charged with CO_2 which further results in the formation of carbonic acid. This accelerates the dissolution of carbonate rocks such as dolomite, limestone and gypsum along groundwater flow path.

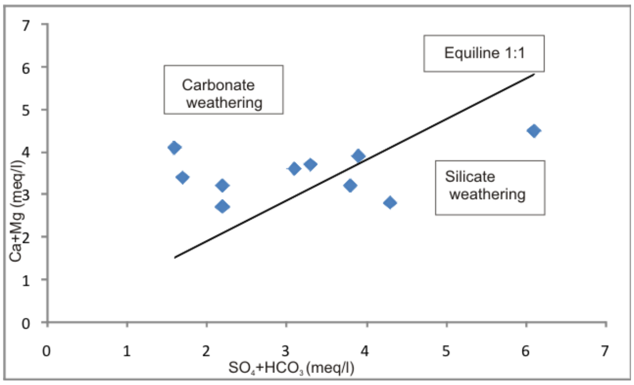

Figure 11. Scatter diagram of (Ca + Mg) vs (SO_4 + HCO_3)

The resultant is the release of Ca^{2+} and Mg^{2+} from the carbonate weathering into groundwater system through recharge. The weathering of calcite minerals which is responsible for the release of the ions is expressed through the following equations:

$$CO_2 + H_2O \rightarrow H_2CO_3 \quad (1)$$

$$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^- \quad \text{(Calcite dissolution)} \quad (2)$$

$$CaMg\ (CO_3) + 2H_2CO_3 \rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^- \quad \text{(Magnesium calcite dissolution)} \quad (3)$$

Sodium and Potassium

When halite dissolution is prominent, Na vs Cl relationship gives a 1:1 ratio [23], however where there is increased concentration of Na than Cl is typically interpreted as Na released from silicate weathering [10]. Figure 12 indicates that most points plotted above the equiline of 1:1 suggesting no halide dissolution. Sodium is relatively less than Cl which indicates absence of much silicate weathering [12]. In the scatter plots of Na vs Ca (Figure 13) and Na vs Mg (Figure 14) scatter diagrams, most points plotted above the equiline of 1:1, thus indicating reduction in Na concentration in groundwater, due to ionic exchange. Further indication of reduction in sodium concentration is shown in Figure 15 where about 80% of the samples plotted below the equiline of 1:1, indicating the reduction of sodium from groundwater.

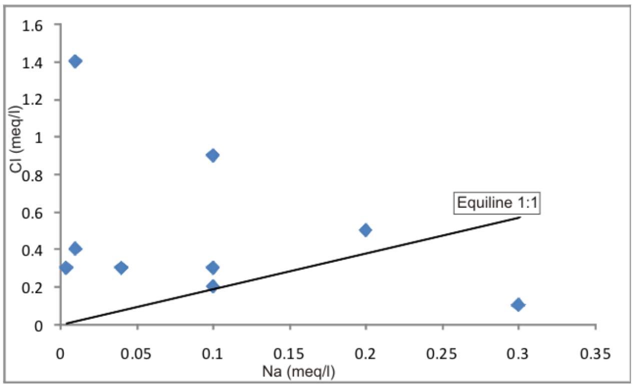

Figure 12. Scatter diagram of Na vs Cl

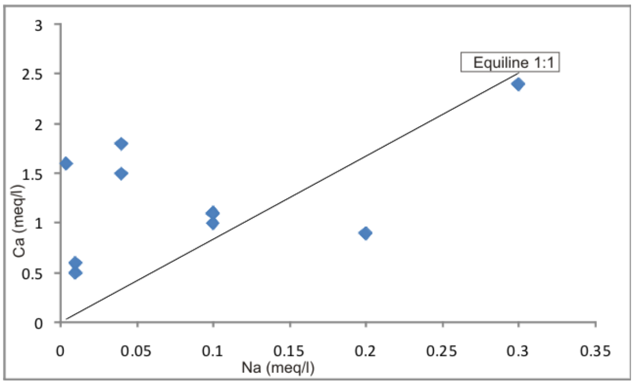

Figure 13. Scatter diagram of Na vs Ca

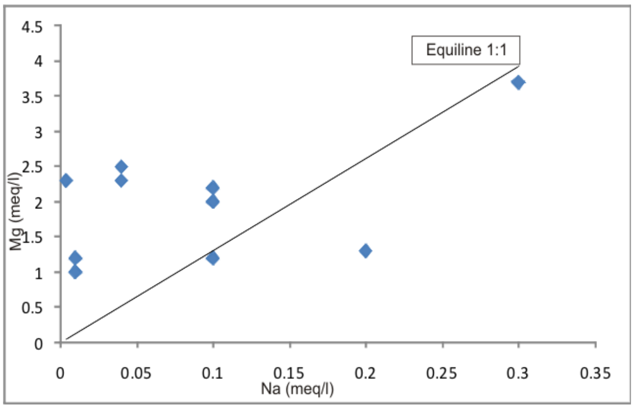

Figure 14. Scatter diagram of Na vs Mg

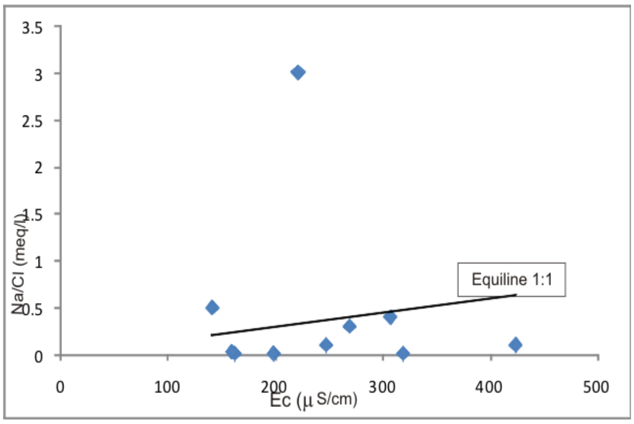

Figure 15. Scatter diagram of EC vs Na/Cl

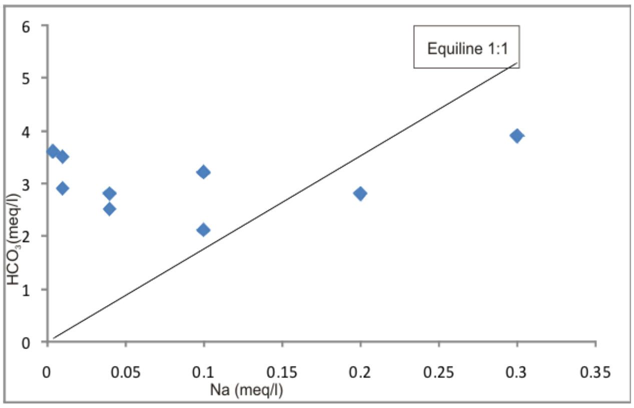

Figure 16. Scatter diagram of Na vs HCO_3

Bicarbonate and Sulphate

The Na vs HCO_3^- scatter diagram (Figure 16) indicates most plots occur above the equiline of 1:1, thus indicating increased HCO_3^- compared to Na which resulted from silicate weathering. The weathering is given by the following equation:

$$2NaAlSi_3O_8 + 2H_2CO_3 + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2Na^+ + 4H_4SiO_4 + 2HCO_3^- \quad (4)$$

Figure 17 shows plot of SO_4 vs Cl, and indicate that most samples plotted above the equiline of 1:1, thus indicating low concentration of chloride. The sulphur concentration in groundwater may be due to oxidation of reduce sulphur gases and sulphate source [2].

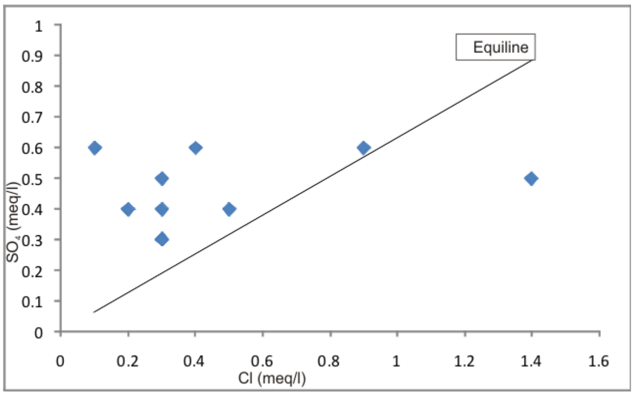

Figure 17. Scatter diagram of Cl vs SO_4

Hydrogeochemical facies

An iron can be considered as type facies when its concentration is within 50 to 100% domain. The characterization of the water in the study area using piper trilinear diagram (Figure 18) indicates that all samples plotted in the region of $Ca-Mg-HCO_3$.The $Ca-Mg-HCO_3$ facies is the dominant water type and belongsto the normal alkaline group, and is related to the geology of the area [26].

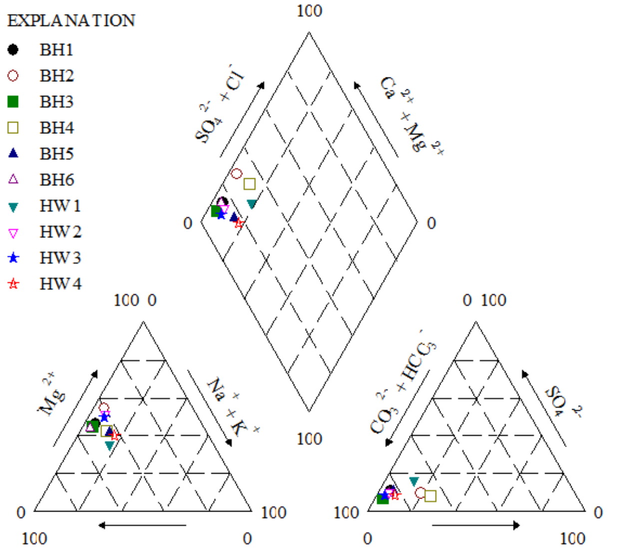

Figure 18. Piper Trilinear diagram of groundwater samples in the study area

4. Conclusion

Result of analysis of twelve water samples from the different sources reveal that the water in the study area is highly polluted due to presence of high coliform. High concentration of nitrate and iron occur in few samples. Hence, the water is unfit for human consumption without treatment. The analysis further revealed that the water is generally good for agricultural and industrial uses. The multivariate statistical analysis using PCA and HCA and rock-water interaction diagrams identified diffused form of contamination, leaching of bed rock geochemistry, salinity, natural mineralization, anthropgenic contamination, silicate weathering and oxidation as the major processes controlling the groundwater chemistry. The water is classified as $Ca-Mg-HCO_3$ facies which belong to the normal alkaline group.

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