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# Hydrogeochemistry and Ground Water Quality Index in Hong and Environs, Adamawa State, North Eastern Nigeria

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**Abstract** – The determination of groundwater quality for human consumption is important for the well-being of the ever-increasing population. The supply of good quality water is one of the important component of groundwater protection and conservation strategies. This research is aimed at understanding the hydrogeochemical processes and ground water quality index (GWQI) in Hong area and environs, north eastern, Nigeria. Fifteen groundwater samples were collected and analyzed chemically and bacteriologically using spectrophotometric, titrimetric and membrane filtration methods. Analytical results indicated that the groundwater in the area is acidic, fresh and moderately hard. The order of abundance of the cations were in $Na^+<K^+<Mg^{2+}<Ca^{2+}$ while the anions were in the order of $Cl^-<HCO_3^->SO_4^{2-}<NO_3^-$. In the Gibbs diagram, sample points fall under rock dominance and weathering zones, which suggested precipitation, induced chemical weathering along with the dissolution of rock-forming minerals. PCA identified four factors that accounts for 73.27% of the total variance. Correlation analysis, PCA and HCA identified municipal wastes, salinity and hardness, anthropogenic contamination and rock-water interaction as the major processes responsible for the modification of groundwater chemistry while scattered plots revealed carbonate weathering, silicate weathering and cation exchange. GWQI values range from 51 to 73.96 which indicated good water category. The piper trilinear diagram classified groundwater samples as Ca-Mg-$HCO_3$ water type. The overall assessment shows that the groundwater in the research area is suitable for drinking purposes.

**Key words:** Hydrogeochemical processes, Groundwater quality, Rock-forming minerals, Water quality index, Hong Area.

## 1. Introduction

The determination of groundwater quality for human consumption is important for the well-being of the ever-increasing population [1]. The supply of good quality water is one of the important component of groundwater protection and conservation strategies and therefore useful in the planning and management of groundwater. Groundwater quality depends on the quality of recharged water, atmospheric precipitation, inland surface water and subsurface geochemical processes [2, 3]. Water pollution not only affects water quality but also threatens human health, economic development, and social prosperity [4]. Hence, evaluation of groundwater quality status for human consumption is important for socio-economic growth and development and also to establish data base for planning future water resource development strategies.

Hydrogeochemistry helps in evaluating the suitable water quality needed for domestic and household purposes [5]. The importance of hydrogeochemical investigation on the water resources of any region cannot be over emphasized. Geology and waste disposal practices have greatly modified the chemistry of surface and groundwater in many areas especially in developing countries of the world. Modification in water chemistry can lead to health problems or unpleasant taste, and may also affect agricultural and industrial activities [6].

[7] worked on the assessment of groundwater quality using factor analysis in Mararaba-Mubi area, Northeastern Nigeria. Their results show that the different water sources are contaminated with respect to phosphate and coliform bacteria. [8] worked on the Assessment of groundwater quality using water quality index and GIS in Jada, northeastern Nigeria. During their research, they found out that the calculated WQI for the groundwater samples falls within the good to very good class. [9] studied the Groundwater Quality and Hydrogeochemistry of Toungo Area, Adamawa State, North Eastern Nigeria.

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Their analytical results revealed that the water from various sources in the research area is unfit for human consumption due to bacteriological pollution. The water quality for agricultural practice indicated that water is good for agricultural practice. [10] worked on the Hydrogeochemical assessment of groundwater in Kaltungo and Environs, northeastern Nigeria. Analytical results from their findings indicate that groundwater samples from Kaltungo and environs are polluted due to high concentrations of iron, fluoride, nitrate, and coliform bacteria. The results further reveal that the water is generally good for agricultural uses. The aim of this research is to evaluate the processes responsible for the modification of groundwater quality and its suitability for drinking purposes in Hong area and environs, northeast Nigeria.

## 2. The Study Area

The study area is located between latitudes 10° 12′ 00" N and 10°17′ 00" N and longitudes 12° 52′ 00" E and 13° 00′ 00" E in Hong Local Government Area of Adamawa state and is part of topographical map Sheet 155, Garkida (Figure 1). The area is accessible by Trunk ‘A’ Gombi – Hong Federal road and is about 151km south of Yola. The area is bounded to the north by Borno State, to the South by Song LGA, to the Southeast and east by Maiha and Mubi North/South LGAs and to the West by Gombi LGA. The area belongs to the tropical hinterland and falls within the Northern Guinea climatological zone. The zone has the following climatic characteristics: Climatic type: Tropical wet and dry seasons (Wet season: April – October/November; dry season: late November – early April); Mean Annual rainfall 700 – 1,050 mm and Mean Annual Temperature: 24 – 30°C [11].

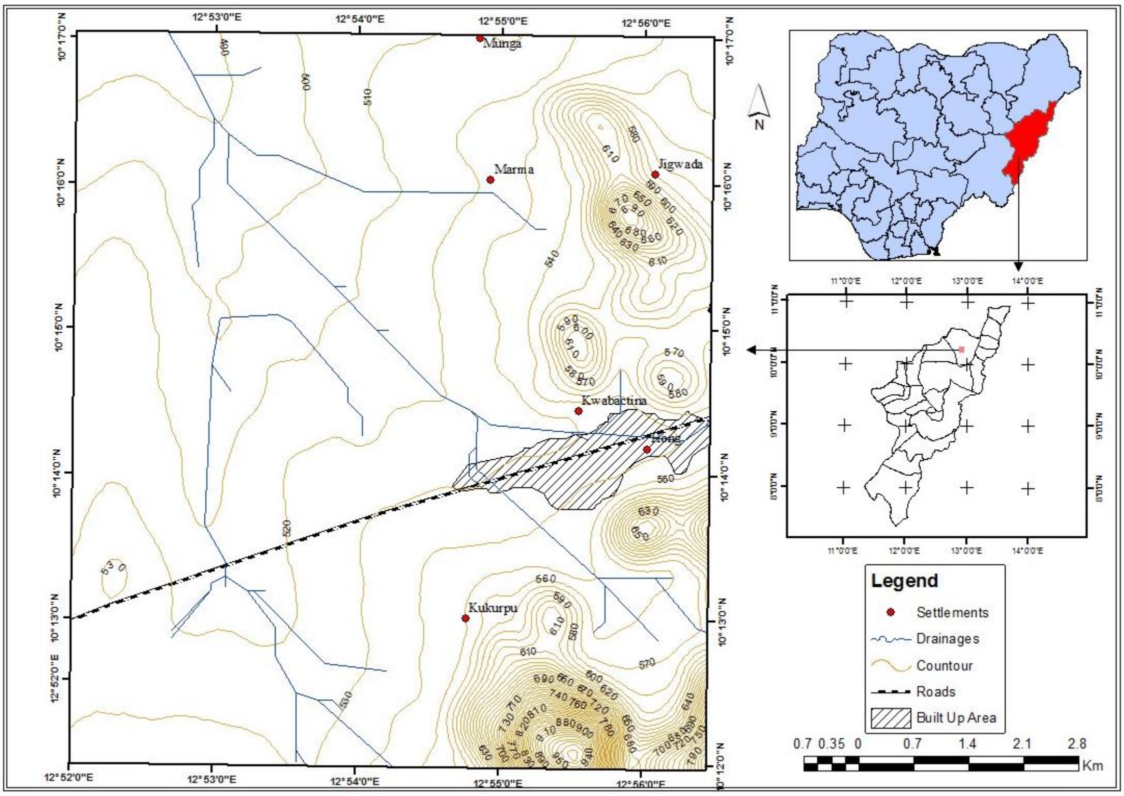

Fig.1 Topographic map of the research area.

The study area lies within the Hawal Massif (otherwise known as Adamawa Massif) in the northeastern sector of Nigeria’s eastern Basement Complex (Figure 2). [12] reported that the rocks within the Hawal Massif are characterized by high grade metamorphic rocks, pervasive migmatization and extensive granite plutonism. Most of the migmatization has been dated at 580 ± 10 Ma. The area is bounded by the Tertiary – Quaternary Chad Basin northwards, the Yola arm of the Cretaceous Benue Basin southward and the Gongola Basin westwards. The area experienced Tertiary magmatism between 7 to 1 Ma [13], during which volcanic and sub-volcanic rocks was emplaced. These volcanic and sub-volcanic rocks are extensions of the Cameroun volcanic line into Nigeria [14]. Earlier during the Mesozoic, transitional alkali basalts was emplaced in Shani area 146 Ma ± 7.3 < age < 127 Ma ±.

[15] reported that the gneisses and migmatites are the older rocks within the Hawal Massif occupying mainly low lying areas, or existing as residual hills. The gneisses are generally strongly foliated and banded, and in some places are commonly dissected by quartzo-feldspatic dykes and veins which impart them with migmatitic characteristics.

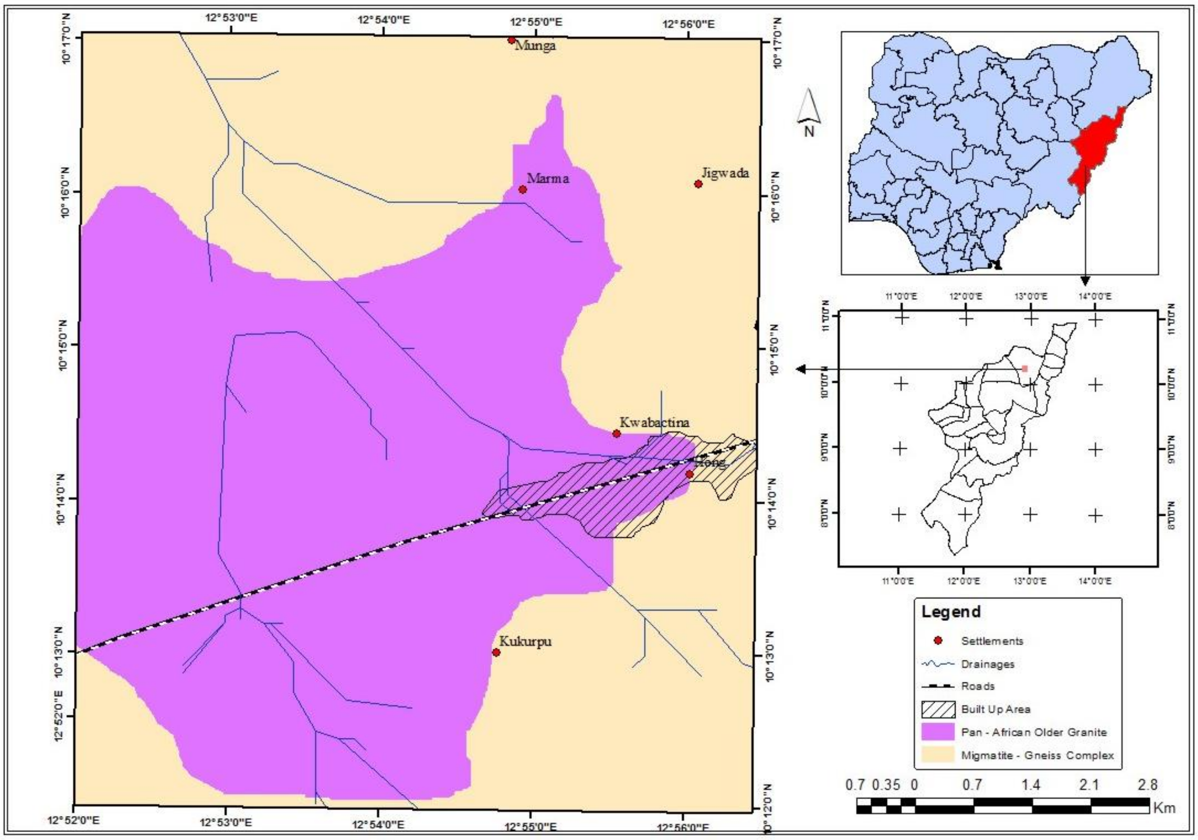

Fig.2 Geological Map of the study area and environs

## 3. Materials and Methods

A total of 15 water samples were collected once during the dry season period from hand-dug wells and boreholes in the research area (Figure 3). The water samples were collected from the discharge of existing hand-dug wells and boreholes according to [16] method. Before the collection of the water samples, the sample containers were rinsed two to three times in the field using the representative groundwater samples according to [17] method. Locations of the monitoring wells were determined using the Global Positioning System. Coordinates of sample location points were recorded and points located on the topographical map of the area.

The temperature of the water was measured using Pen pH and temperature meter and pH model CT 6021 (Exact Instrument). $CO_3^{2-}$, $HCO_3^-$ and total hardness were measured using EDTA Titrimetric method (HACH Digital Titrator model 16900 with selected titration cartridges). Total dissolve solids was measured using PENTDS Meter model CT3061 (Exact instrument) while electrical conductivity was measured using Pen Conductivity Meter model CT3030 (Exact instruments). The major cations and anions were determined using HACH Digital Spectrophotometer (model 2040, USA) in accordance with the international standard method. Turbidity was measured using turbidimetric method using mobile digital turbidity meter model SGS-200BS (PELMedical, U.S.A).

## 3.1 Pearson correlation

Pearson correlation measure of the linear correlationbetween two variables X and Y. Pearson correlation coefficient is commonly used to measure strength between variables [18]. According to [19, 20], samples showing correlation of r>0.7 are considered to be strongly correlated, whereas r>0.5 – 0.7 shows moderate correlation. The strong correlation is an indication of common source or origin. For the water parameters in the research area the correlations between variables were computed using SPSS statistics software (Version 16.0).The Pearson correlation formula [21] is given as;

$$r = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{[N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)^2]}} \qquad 1$$

where r is Pearson correlation, N is number of pairs of scores, $\sum XY$ is sum of products of paired scores, $\sum X$ is sum of x scores, is sum of y scores, $\sum X^2$ is sum of squared x scores and $\sum Y^2$ is sum of squared y scores.

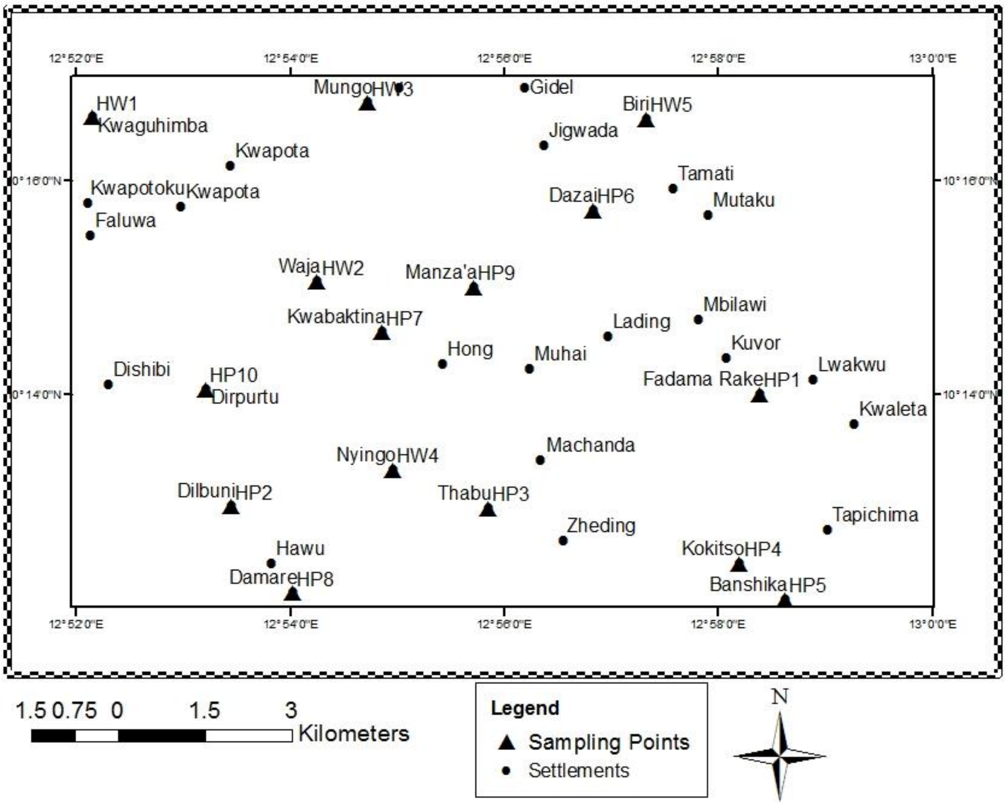

Fig. 3 Map showing the location of the water samples in the research area

## 3.2 Principal Component Analysis

Principal component analysis (PCA) is an orthogonal linear transformation that transforms the variables to a new coordinate system [20]. PCA) provides an objective way of finding indices of variance so that the variation in the data can be accounted for as concisely as possible [20]. PCA of the variable was performed using SPSS software to extract the significant components. PCA is generated through expression as:

$$r = y_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + \cdots a_{im}x_{mj} \qquad 2$$

where y is component score, a is component loading, x is measured value of the variable, i is component number, j is sample number, and m is total number of variables. The component weights represent correlation between the PCs and the variables [22].

## 3.3 Hierarchical Cluster Analysis

The Hierarchical Cluster Analysis (HCA) is way of grouping a set of objects in such a way that objects in the same group are more similar to each other than to those in other groups. HCA is being used to group objects into classes or clusters on the basis of similarities within the class or dissimilarities [9, 20, 23]. Short distance shows the two objects are similar or close together whereas a long distance indicates dissimilarity [24]. The HCA according to [25] with squared Euclidean distances was applied to detect multivariate similarities in groundwater quality of the research area. The method of computing the squared Euclidean distance can be expressed as:

$$d_{ij}^2 = \sum_{k=1}^{n} \left(Z_{ik} - Z_{jk}\right)^2 \qquad 3$$

where, $d_{ij}^2$ is the squared Euclidean distance; $Z_{ik}$ is the value of k variable for the object i;$Z_{jk}$ is the value of k variable for the object j; and n is the number of variables [26].

## 3.4 Water quality index calculation

The water quality index (WQI) is used to access the influence of natural and anthropogenic activities based on the important parameters on groundwater chemistry [20, 27]. To estimate the WQI, the weight was assigned to the physicochemical parameters according to the parameters' relative importance in the overall quality of water for drinking water purposes. The weight ranges from 1 to 5. The maximum weight of 5 was assigned to parameters such as nitrate and total dissolved solids, weight 4 for pH, EC, $SO_4$, weight 3for $HCO_3$, TH and Cl, weight 2 for Ca, Na, K and weight 1 for Mg [3, 20]. The relative weight is computed from the equation below;

$$W_i = w_i / \sum_{i=1}^{n} w_i \qquad 4$$

where $W_i$ is the relative weight $w_i$ is the weight of each parameter n is the number of parameters.

The quality rating scale for each parameter is calculated by dividing its concentration in each water sample by its respective standards [28] and multiplied the results by 100, equation five.

$$q_i = (C_i/S_i)x100 \quad 5$$

where $q_i$ is the quality rating $C_i$ is the concentration of each chemical parameter in each sample in milligrams per litre $S_i$ is the World Health Organization standard for each chemical parameter in milligrams per litre according to the guidelines of [28]. For computing the final stage of WQI, the SI is first determined for each parameter equation six. The sum of SI values gives the water quality index for each sample, equation seven.

$$SI_i = W_i \text{ x } q_i \quad 6$$

$$WQI = \sum SI_i \quad 7$$

where $SI_i$ is the sub-index of ith parameter qi is the rating based on concentration of ith parameter n is the number of parameters. WQI <50 is excellent; 50 to 100 is good water; 100 to 200 poor water; 200 to 300 is very poor water and >300 indicates water that is unsuitable for human consumption [20, 27, 29].

## 3.5. Rock-water interaction

During weathering and circulation of water in rocks and formations, ions leached out and dissolved in groundwater [30, 31]. The geological formations, water-rock interaction and mobility of ions are prime factors influencing the geochemistry of groundwater [31]. Different chemical processes occur during rock-water interaction, including dissolution/precipitation, ion exchange processes, oxidation and reduction. These geochemical processes are responsible for the spatial distribution of groundwater chemistry [20]. Water-rock interaction reflects the differences in mineral composition of the aquifer, presence of fissures, faults and cracks which affect groundwater movement in the subsurface medium [32].

## 3.6. Hydrogeochemical facies

Piper diagrams [33] are combination of anion and cation triangle that lie on a common baseline and diamond shape between can be used to make reasonable conclusion as to the origin of the water from the analysis and to characterize different water types. Piper diagram divides waters into four water types. Water that plots at the top of the piper diagram is high in $Ca^{2+}$ + $Mg^{2+}$ and $Cl^-$ +$SO_4^{2-}$ and the area represents permanent hardness water type. The water that plots near the left corner of the piper diagram is rich in $Ca^{2+}$ + $Mg^{2+}$ and $HCO_3^-$ and the region is of temporary hardness water type. Water that plots at the lower corner of the piper is composed of alkali carbonates ($Na^+$ + $K^+$ and $HCO_3^-$ + $CO_3^{2-}$). Water that plots lying near the right-hand side of the piper is considered as saline water type ($Na^+$ + $K^+$ and Cl- + $SO_4^{2-}$) [34]. The piper diagram graphically represent the chemical equilibrium between cations ($Ca^{2+}$, $Mg^{2+}$, $Na^+$ and $K^+$) and anions ($Cl^-$, $SO_4^{2-}$, $CO_3^{2-}$ and $HCO_3^-$) in water samples and also describe the presence of main contributor ions and chemical reactions taking place in the water. The diagram composed of two lower triangles of cations and, anions and middle quadrilateral. Quadrilateral or diamond shape indicates the combined distribution of both ions (cations and anions) and final water type of sources. Such diagrams may describe various hydrochemical processes like base cation exchange, cement pollution, mixing of natural waters, sulfate reduction, saline water (end-product water) and other related hydrochemical problems.

## 4. Results and Discussion

Figure 4 indicates that groundwater flow takes place from the recharge area at Fadama Rake, Lwakwu, Kwaleta and Kuvor in the east and flows towards Mutuku in the north and also flows towards Lading and Muhai in the central part of the area and also flows towards Tapichima down to Banshika. Groundwater flow also takes place from Hawu in the south and flows towards Nyingo and Dilbuni in the south. Recharge areas occur around Fadama Rake, Lwakwa and Kwaleta in the east, Dazai in the north and Kwaguhinba in the northwest. Discharge areas occur around Dishibi, and Kwapota areas. The flow of groundwater is highly influenced by the hydraulic heads of the recharge area. Similar finding was observed by [35] on the floodplain of River Benue, north eastern Nigeria.

The groundwater quality results for the physical, chemical and micro-biological analysis of the fifteen (15) groundwater samples from the research area is presented in Table 1.

Based on the mean values of the cations and anions the order of abundance of the cations is as $Na^+<K^+<Mg^{2+}<Ca^{2+}$ and $Cl^-<HCO_3^->SO_4^{2-}<NO_3^-$ for the anoins. The pH values range between 5.37 to 7.99 with mean value of 6.12, this suggests that, the groundwater condition is acidic. The TDS values range between 32mg/l to 79.6mg/l with mean value of 55.67mg/l, this indicates that, the fresh groundwater [36]. The TH values range between 51.72mg/l to 81.67mg/l with mean value of 70.37mg/l, this shows that, the groundwater condition is moderately hard [37] cited in [38].

## 4.1 Multivariate Statistical Analysis

The multivariate statistical analysis is able to reveal the processes of groundwater quality in the research area. Statistical analysis was performed on the physico-chemical parameters and major ion concentration to find the relationship and differences between the groundwater samples of the research area (Table 2). The correlation matrix represents the first step of the factor analysis [39]. Strong to nearly perfect correlation exist between Ec and TDS (r=0.991), TH and TDS (r=0.842), TH and EC (r=0.835), Ca and TH (r=0.706), and Coliform and Na (r=0.776). The strong to nearly perfect correlations exhibited among the chemical parameters is an indication of common source. The correlation between $NO_3$ and Cl (r=0.703) revealed strong positive correlation. According to [40, 41], if correlation between nitrate and chloride is greater than 0.35, the effect of municipal waste is suggested. The strong positive correlation between nitrate and chloride therefore is an indication of the influence of municipal wastes in the degradation of groundwater quality [6]. The strong correlation between TDS and EC is an approximate relationship for most natural groundwater [42].

Principal Component Analysis (PCA) is performed on the fifteen (15) data set (Table 3) to identify the major variables affecting groundwater quality in the research area and it indicates four factors. Factor 1 accounts for about 28.94% of total variance and is characterised by strong positive loading with respect to TDS, EC, TH, Fe and Ca, and strong negative loading with respect to $HCO_3$ and Cu. Factor 1 is interpreted as salinity and total hardness influenced by Ca and Fe [20, 43]. Factor 2 accounts for about 21.20% of total variance and is characterized by strong positive loading with respect to Na, Cl, $SO_4$, $NO_3$ and coliform. Factor 2 is interpreted as anthropogenic contamination. Factor 3 accounts for about 12.48% of total variance and is characterized by strong positive loading of K and moderate positive loading of Mg, and moderate negative loading with respect to temperature and silicates. The high positive loading with respect to K suggests pollution from application of potash fertilizers on agricultural lands [39]. Factor 4 accounts for about 10.66% of total variance and is characterized by strong positive loading with respect to Magnesium and Manganese. The combination of Mg and Mn is an indication of weathering of bed rock materials that consists of dark coloured minerals from igneous rocks.

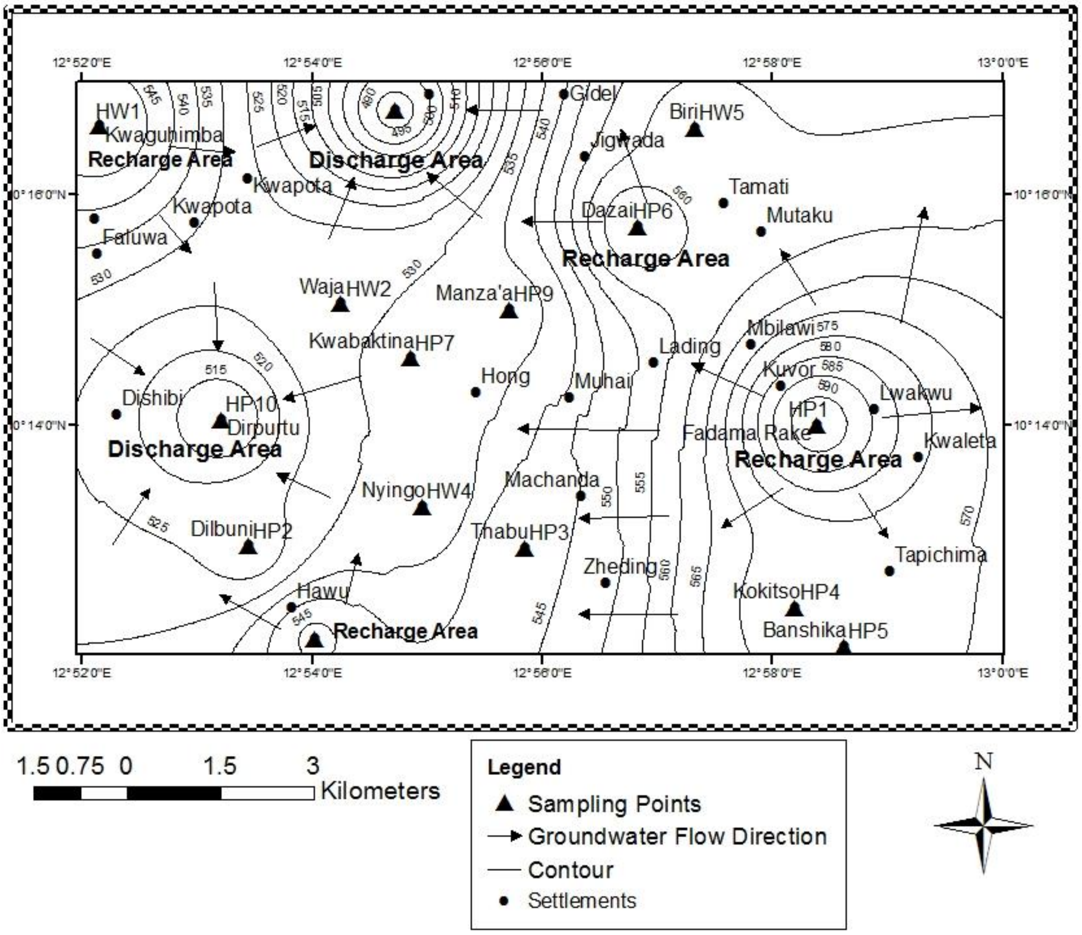

Fig.4 Hydraulic head distribution in unconfined aquifers in the research area.

The result of cluster analysis is shown in Figure 5, and indicates two clusters. Cluster 1 is subdivided into two sub clusters. Sub cluster 1 comprises of TDS, electrical conductivity, total hardness, iron, manganese and silicates and sub cluster 2 comprises of temperature and fluoride. Cluster 1 is ascribed as rock-water interaction [9, 20]. Cluster 2 is subdivided into two clusters; the first sub cluster has close similarities between sodium, coliform, chloride, sulphate and nitrate, and the second sub cluster shows similarities between potassium, magnesium, carbonate, bicarbonate, copper and pH. Cluster 2 is interpreted as anthropogenic contamination [20].

Table 1 Physical, Chemical and Micro-Biological Analysis of Water Samples in the Study Area

| SN | Sample Point | Temp. (°C) | pH | Tubidity (NTU) | TDS (mg/l) | EC (μ/cm) | $CO_3^{2-}$ (mg/l) | $HCO_3^{2-}$ (mg/l) | TH (mg/l) | $K^+$ (mg/l) | $Mg^{2+}$ (mg/l) | $Na^+$ (mg/l) | $Fe^{2+}$ (mg/l) | $Ca^{2+}$ (mg/l) | $Cu^{2+}$ (mg/l) | F (mg/l) | $Mn^{2-}$ (mg/l) | $Cl^-$ (mg/l) | $SO_4^{2-}$ (mg/l) | $NO_3^{2-}$ (mg/l) | $SiO_2$ (mg/l) | Coliform Count |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Fadama Rake (HP) | 28.11 | 5.86 | 0.017 | 68.8 | 101.02 | 0 | 317 | 76.67 | 9.1 | 32.06 | 5.12 | 0.905 | 48.67 | 0.48 | 1.41 | 0.044 | 112.01 | 34 | 92.6 | 31 | 19 |
| 2 | Kwaguhimba (HW) | 24.62 | 6.1 | 0.075 | 71 | 111.7 | 0 | 293.6 | 79.52 | 7.6 | 29.67 | 1.67 | 0.677 | 52.18 | 0.307 | 2.091 | 0.016 | 56.21 | 27.62 | 46.8 | 28.11 | 8 |
| 3 | Dilbuni (HP) | 27.66 | 6.58 | 0.103 | 79.6 | 121.07 | 0 | 218 | 74.41 | 7.7 | 39.66 | 3.01 | 1.04 | 33.72 | 1.03 | 1.327 | 0.1 | 37.86 | 30.07 | 53.42 | 19,62 | 11 |
| 4 | Waja (HW) | 20.4 | 5.42 | 0.552 | 61.7 | 96.28 | 1.1 | 421 | 75 | 8.3 | 37 | 2.16 | 0.893 | 41.11 | 0.67 | 1.407 | 0.092 | 41.72 | 23.16 | 80.11 | 29.72 | 11 |
| 5 | Thabu (HP) | 29 | 6.11 | 0.011 | 58.9 | 86.11 | 0 | 331 | 76.11 | 6.2 | 28.63 | 1.02 | 1.037 | 50.6 | 0.41 | 2.662 | 0.101 | 52.83 | 28 | 73.62 | 34.01 | 6 |
| 6 | Kokitsa (HP) | 27.6 | 6.43 | 0.501 | 60 | 86.92 | 1.2 | 297 | 69.27 | 7 | 30.07 | 0.93 | 1.02 | 42.02 | 0.38 | 2.508 | 0.063 | 27.67 | 21.47 | 41.33 | 23.42 | 3 |
| 7 | Munga (HW) | 22.4 | 5.8 | 0.597 | 48.6 | 69.88 | 2.1 | 376 | 66.21 | 9.6 | 28.92 | 3.16 | 0.561 | 40.01 | 0.78 | 1.443 | 0.009 | 33 | 30 | 50.07 | 20.2 | 12 |
| 8 | Banshika (HP) | 27.09 | 5.44 | 0.039 | 53.1 | 77.89 | 0 | 377 | 69 | 6.51 | 31.37 | 1.2 | 0.778 | 37.62 | 0.55 | 4.537 | 0.042 | 21.62 | 24.26 | 49.1 | 19.77 | 6 |
| 9 | Dazel (HP) | 26.93 | 6.01 | 0.618 | 49.63 | 75.92 | 2 | 410 | 64.42 | 7.8 | 39.67 | 1.22 | 0.58 | 30 | 0.6 | 0.97 | 0.05 | 40 | 18.07 | 77.62 | 24.01 | 3 |
| 10 | Kwabaktina (HP) | 28 | 5.37 | 0.092 | 51.67 | 76.8 | 0 | 213 | 73.11 | 8 | 31 | 1.12 | 1 | 47 | 0.098 | 1.887 | 0.095 | 26.87 | 17.57 | 39.66 | 33.01 | 4 |
| 11 | Damire (HP) | 28.27 | 6 | 0.501 | 70 | 107.62 | 0 | 210 | 81.67 | 8.6 | 34.21 | 1.02 | 1.21 | 51.03 | 0.043 | 1.601 | 0.008 | 19.73 | 23.02 | 40 | 29.35 | 3 |
| 12 | Manza'a (HP) | 27.18 | 6.51 | 0.617 | 42.06 | 66.11 | 1 | 300 | 69.92 | 9.8 | 35.02 | 1.1 | 0.67 | 41.6 | 0.903 | 2.583 | 0.059 | 29.5 | 21.63 | 43.42 | 21.62 | 5 |
| 13 | Nyinga (HW) | 26 | 5.92 | 0.9 | 47.15 | 73.19 | 1.4 | 309.4 | 64.29 | 5.96 | 29.97 | 0.63 | 0.59 | 39.11 | 0.622 | 2.1 | 0.023 | 31.21 | 23.72 | 51.27 | 30 | 13 |
| 14 | Dirparta (HP) | 27.93 | 6.27 | 0.025 | 32 | 51.07 | 0 | 466 | 51.72 | 6.8 | 23.82 | 0.49 | 0.72 | 35.62 | 0.41 | 1.6 | 0.007 | 53.17 | 28.92 | 49.88 | 27.02 | 5 |
| 15 | Biri (HW) | 24.98 | 7.99 | 0.42 | 40.9 | 62.69 | 0 | 393.01 | 64.18 | 6.17 | 27.63 | 0.58 | 0.49 | 39.62 | 0.87 | 1.82 | 0.011 | 34.88 | 20.53 | 63.42 | 31.07 | 8 |
|  | Average | 26.41 | 6.12 | 0.34 | 55.67 | 84.28 | 0.59 | 328.80 | 70.37 | 7.68 | 31.91 | 1.63 | 0.81 | 41.99 | 0.54 | 2.00 | 0.05 | 41.22 | 24.80 | 56.82 | 27.31 | 7.8 |
|  | WHO, 2011 | 30-35 | 6.5-8 | 0-5 | 0-500 | 0-1000 | 0-120 | 1-1000 | 0-150 | 0-200 | 0-200 | 0-200 | 0-0.3 | 0-200 | 0-2 | 0-1.5 | 0-0.4 | 0-250 | 0-100 | 50-70 |  | 0-3 |

Table 2 Correlation of physical, chemical and micro-biological parameters for the groundwater in the research area

| | Temp (°C) | pH | TDS (mg/l) | EC (µs/cm) | HCO$_3$ (mg/l) | TH (mg/l) | K (mg/l) | Mg (mg/l) | Na (mg/l) | Fe (mg/l) | Ca (mg/l) | Cu (mg/l) | F (mg/l) | Mn (mg/l) | Cl (mg/l) | SO$_4$ (mg/l) | NO$_3$ (mg/l) | SiO$_2$ (mg/l) | Coli Form |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp | 1 | | | | | | | | | | | | | | | | | | |
| pH | 0.094 | 1 | | | | | | | | | | | | | | | | | |
| TDS | 0.055 | -0.209 | 1 | | | | | | | | | | | | | | | | |
| EC | 0.019 | -0.187 | **0.991**** | 1 | | | | | | | | | | | | | | | |
| HCO3 | -0.419 | 0.080 | **-0.609*** | **-0.598*** | 1 | | | | | | | | | | | | | | |
| TH | 0.023 | -0.256 | **0.842**** | **0.835**** | **-0.672**** | 1 | | | | | | | | | | | | | |
| K | -0.213 | -0.266 | 0.191 | 0.191 | -0.212 | 0.324 | 1 | | | | | | | | | | | | |
| Mg | -0.079 | -0.182 | 0.498 | **0.522*** | -0.287 | 0.415 | 0.4 | 1 | | | | | | | | | | | |
| Na | -0.162 | -0.239 | **0.528*** | 0.483 | -0.119 | 0.374 | **0.572*** | 0.288 | 1 | | | | | | | | | | |
| Fe | 0.441 | -0.304 | **0.640*** | **0.607*** | **-0.609*** | **0.614*** | 0.086 | 0.234 | 0.135 | 1 | | | | | | | | | |
| Ca | 0.128 | -0.169 | 0.403 | 0.393 | -0.476 | **0.706**** | 0.158 | -0.292 | 0.129 | 0.453 | 1 | | | | | | | | |
| Cu | -0.354 | 0.445 | -0.151 | -0.141 | 0.288 | -0.298 | 0.087 | 0.300 | 0.222 | -0.499 | **-0.619*** | 1 | | | | | | | |
| F | 0.224 | -0.14 | -0.127 | -0.165 | -0.004 | 0.030 | -0.363 | -0.270 | -0.332 | 0.033 | 0.118 | -0.079 | 1 | | | | | | |
| Mn | 0.142 | -0.254 | 0.352 | 0.320 | -0.290 | 0.358 | 0.009 | 0.480 | 0.134 | **0.515*** | 0.002 | 0.102 | 0.054 | 1 | | | | | |
| Cl | 0.105 | -0.04 | 0.238 | 0.222 | 0.164 | 0.134 | 0.168 | -0.112 | **0.683**** | 0.003 | 0.274 | -0.029 | -0.305 | -0.001 | 1 | | | | |
| SO4 | 0.014 | -0.076 | 0.346 | 0.321 | 0.056 | 0.111 | 0.16 | -0.217 | **0.680**** | 0.100 | 0.189 | 0.159 | -0.104 | -0.128 | **0.664**** | 1 | | | |
| NO3 | -0.17 | -0.032 | 0.141 | 0.124 | 0.435 | 0.083 | 0.023 | 0.244 | 0.510 | -0.094 | -0.066 | 0.229 | -0.328 | 0.232 | **0.703**** | 0.292 | 1 | | |
| SiO2 | 0.175 | 0.089 | 0.253 | 0.278 | -0.276 | 0.316 | -0.307 | -0.166 | -0.012 | 0.363 | 0.527 | -0.405 | -0.335 | 0.292 | 0.351 | 0.031 | 0.328 | 1 | |
| Coli | -0.333 | -0.085 | 0.269 | 0.253 | 0.058 | 0.132 | 0.189 | 0.013 | **0.776**** | -0.175 | 0.07 | 0.376 | -0.251 | -0.05 | **0.648**** | **0.675**** | **0.530*** | 0.193 | 1 |

Table 3 Rotation Principal Component Analysis (PCA) loading matrix

| Parm. | Component | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Temp | 0.284 | -0.241 | **-0.555** | -0.087 |
| pH | -0.415 | -0.036 | -0.353 | -0.194 |
| TDS | **0.860** | 0.266 | 0.188 | 0.112 |
| Cond | **0.842** | 0.252 | 0.194 | 0.126 |
| $HCO_3$ | **-0.799** | 0.317 | 0.021 | 0.036 |
| TH | **0.882** | 0.127 | 0.198 | 0.198 |
| K | 0.243 | 0.171 | **0.748** | -0.003 |
| Mg | 0.150 | -0.015 | **0.564** | **0.731** |
| Na | 0.266 | **0.775** | 0.451 | -0.127 |
| Fe | **0.804** | -0.114 | -0.221 | 0.212 |
| Ca | **0.872** | 0.165 | -0.173 | -0.194 |
| Cu | **-0.751** | 0.211 | 0.349 | 0.012 |
| F | 0.086 | -0.442 | -0.080 | -0.213 |
| Mn | 0.254 | 0.023 | -0.131 | **0.729** |
| Cl | 0.146 | **0.896** | -0.134 | -0.122 |
| $SO_4$ | 0.152 | **0.678** | 0.031 | **-0.608** |
| $NO_3$ | -0.134 | **0.844** | -0.041 | 0.434 |
| Silicates | 0.352 | 0.375 | **-0.678** | 0.265 |
| Coliform | -0.010 | **0.832** | 0.200 | -0.241 |
| % of Var | 28.941 | 21.197 | 12.475 | 10.657 |
| Cum % | 28.941 | 50.138 | 62.613 | 73.27 |

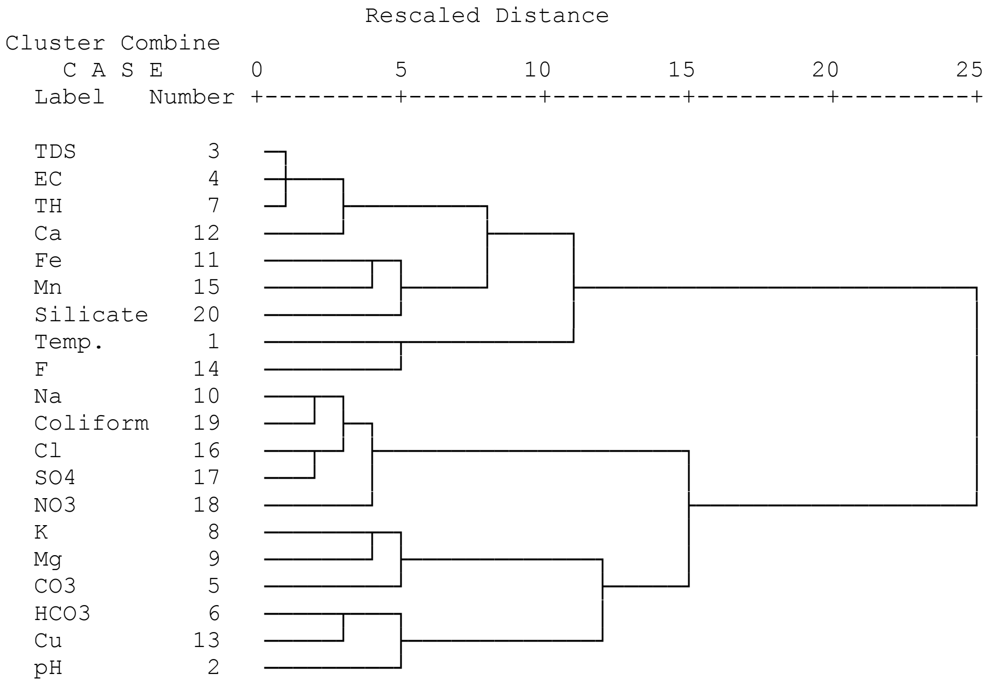

Fig.5 Dendrogram of groundwater samples in the study area

## 4.2 Rock-water Interaction

The use of scattered plots for Log TDS vs Na/(Na+Ca) and Log TDS vs Cl/(Cl+HCO3) [44] is used to interpret the effect of hydrogeochemical processes such as precipitation, rock–water interaction and evaporation on groundwater geochemistry. Figures 6 and 7 indicate that most points plotted in the region of rock-dominance and weathering zones, thus indicating precipitation derived from rock-water interaction [31].

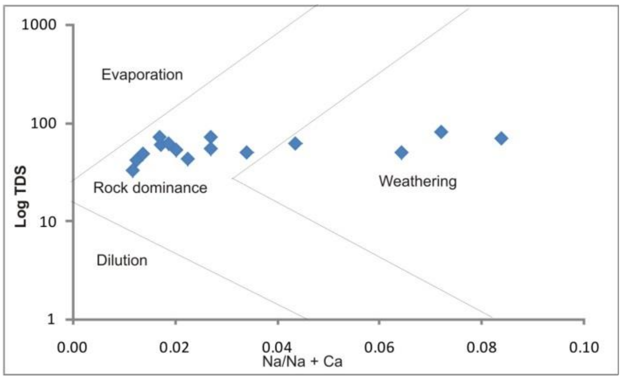

Fig. 6 Cations plot in Gibbs diagram

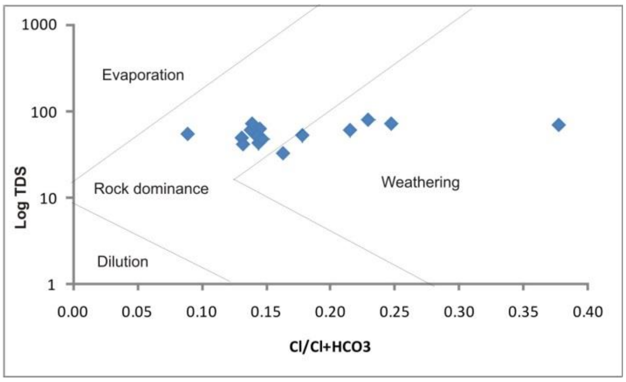

Fig. 7 Anions plot in Gibbs diagram

## 4.3. Calcium and Magnesium

Calcium and Magnesium are the dominant cations in groundwater which are influenced by the dissolution of carbonate minerals, which is explained through the scattered plots of Ca+Mg vs $HCO_3$+$SO_4$ [45]. Figure 8A scattered plot of (Ca+Mg) vs ($HCO_3$+$SO_4$) for the research area indicates that most points lie above equiline of 1:1, thus indicating carbonate weathering. Carbonate weathering are caused by rainwater charged with $CO_2$ and become rich in carbonic acid. This accelerates the dissolution of carbonate rocks such as dolomite, limestone and gypsum along groundwater flow direction [9]. The process is responsible for the increase in the concentrations of Ca, Mg and $HCO_3$ content in groundwater. The release of these ions is shown by the equation as follows:

$$CaMg\,(CO_3)_2 + 2H_2CO_3 = Ca^{2+} + Mg^{2+} + 4HCO_3^- \qquad 8$$

## 4.4. Sodium and Potassium

Generally, when halite dissolution is the process, $Na^+$ vs $Cl^-$ relationship gives 1:1 ratio [31]. The plots of $Na^+$ vs $Cl^-$ scatter diagram (Figure 8B) in the research area suggests that most points plotted above the equiline. Thus, indicating absence of halite dissolution [9, 32]. Sodium is less than chloride indicating absence of much silicate weathering [46]. Figure 8C shows plot of $SO_4$ vs Cl, and indicate that most points plotted below the equiline of 1:1, thus indicating high concentration of Chloride. The chloride concentration in groundwater may be due sewage and other waste outlets [47]. The scatter plots of Na vs $HCO_3^-$ (Figure 8D) shows that most points occur above equiline of 1:1, thus suggesting increase $HCO_3^-$ compared to Na which resulted from silicate weathering. The scattered plots of Na vs Ca (Figure 8E) and Na vs Mg (Figure 8F) scatter diagrams indicate that most points plotted above the equiline of 1:1, which shows reduction in sodium concentration in groundwater, due to ionic exchange.

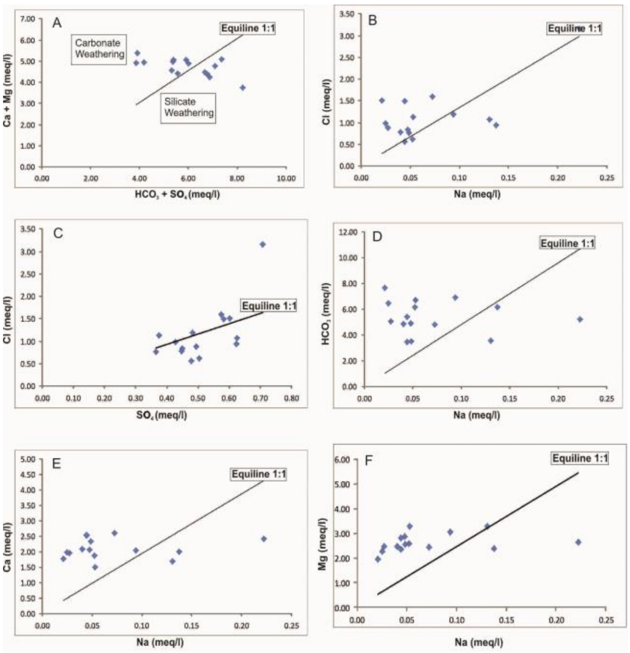

Fig. 8 Relationship between major cations and anions in groundwater in the research area. (a) Relation between Bicarbonate and Sodium; (b) Relation between Magnesium and Sodium; (c) Relation between Calcium and Sodium; Relation between Chloride and Sodium; Relation between Chloride and Sulphate; Relation between Ca+$SO_4$ and $HCO_3$+$SO_4$. Calcium, Magnesium, Sodium and Potassium participate in cation exchange which is important in explaining processes of groundwater chemistry.

Piper trilinear diagrams were prepared to classify the water quality of selected sources in the research area. The diagram classified the hydrochemical facies in account of prominent ions contributed in the water quality. The groundwater samples were plotted on piper trilinear diagram (Figure 9) to classify the water geochemically.

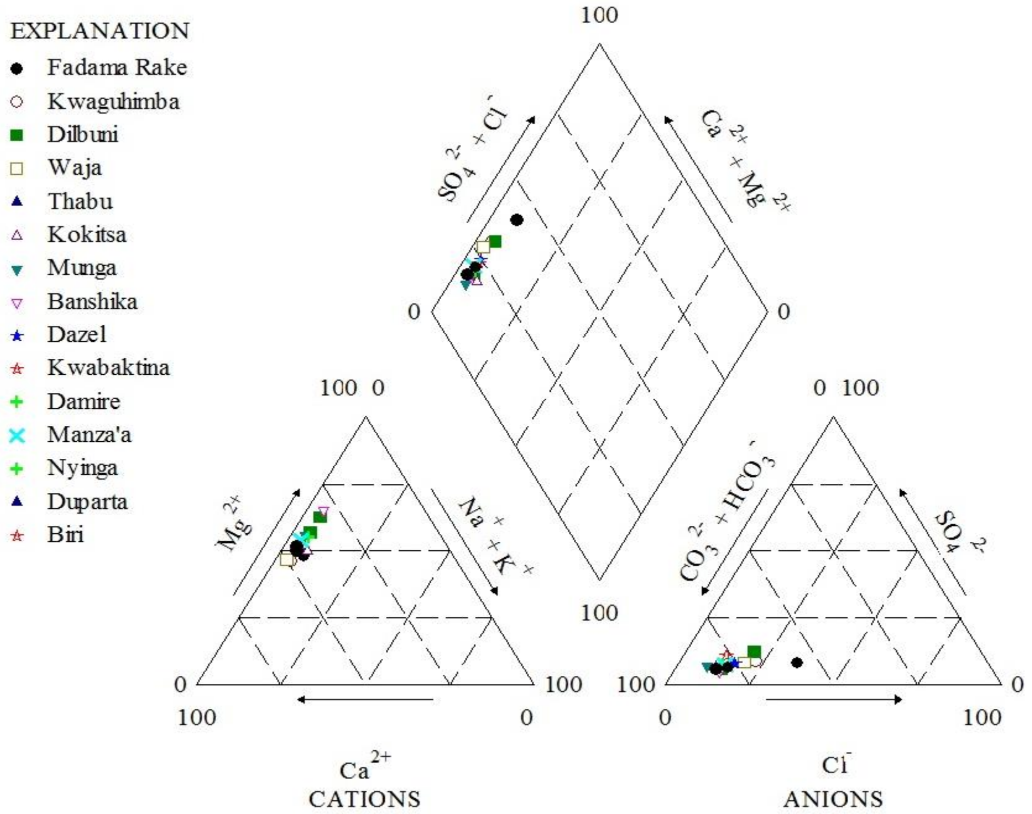

Fig. 9 Piper diagram showing groundwater classification in the research area

The classification system shows the anion and cation facies in terms of major ion percentage. The result shows that the groundwater samples fall in the field of Ca -Mg -$HCO_3$ type of water. The Ca - Mg -$HCO_3$ is regarded as recently recharge water and its sources are related to atmospheric precipitation and dissolution of silicate minerals [7].

The Water Quality Index (WQI) ranges from 51 to 73.96 (Table 4). The WQI values obtained range between 51 and 74 which suggest that, the water in the research area falls in the range of good water and is suitable for human consumption.

Table 4 Computed Water Quality Index (WQI) for Individual Groundwater Samples

| Sample Points | WQI | Remarks |
|---|---|---|
| Fadama Rake (HP1) | 69.09 | Good water |
| Kwaguhimba (HW1) | 56.06 | Good water |
| Dilbuni (HP2) | 66.08 | Good water |
| Waja (HW2) | 66.66 | Good water |
| Thabu (HP3) | 73.96 | Good water |
| Kokitsa (HP4) | 64.76 | Good water |
| Munga (HW3) | 51.00 | Good water |
| Banshika (HP5) | 70.08 | Good water |
| Dazel (HP6) | 54.35 | Good water |
| Kwabaktina (HP7) | 58.41 | Good water |
| Damire (HP8) | 62.19 | Good water |
| Manza'a (HP9) | 59.08 | Good water |
| Nyinga (HW4) | 53.64 | Good water |
| Dirpurtu (HP10) | 54.18 | Good water |
| Biri (HW5) | 55.32 | Good water |

## 5. Conclusion

The groundwater quality in Hong and environs has been evaluated for its hydrogeochemical and suitability for human consumption purposes. Hydrochemical results reveal that the groundwater in the research area is acidic and soft. Analytical results indicated that the groundwater in the area is acidic, fresh and moderately hard. The sequence of the abundance of the major ions is in the following order: $Na^+<K^+<Mg^{2+}<Ca^{2+}$ for the major cations. On the other hand, for the major anions, the order was $Cl^-<HCO_3^->SO_4^{2-}<NO_3^-$. The plots of log TDS vs. Na/(Na + Ca) and log TDS vs Cl/(Cl + $HCO_3$) indicates that most points plotted in the region of rock-dominance and weathering, thus suggesting precipitation induced chemical weathering along with the dissolution of rock-forming minerals. PCA and HCA identified salinity and hardness, anthropogenic contamination and rock-water interaction while scatter plots identified carbonate weathering, silicate weathering and cation exchange as the major processes responsible for the modification of groundwater chemistry. Piper diagram indicates that the water from all selected sources is predominantly influenced by $Mg^{2+}$ and $HCO_3^-$ ions i.e. Ca-Mg-$HCO_3$ hydrochemical facies which represent equal dominance of alkaline earth metals and weak acid and thus water quality shows the nature of carbonate hardness. The computed values of WQI reveal that the groundwater in the research area falls in the range of good water and is suitable for human consumption.The overall assessment shows that the groundwater in the research area is suitable for domestic purposes.

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