

Assessment of Groundwater Quality and its Suitability for Domestic and Agricultural Purposes in parts of the Central Region, Ghana

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Abstract

Groundwater in parts of the Central Region of Ghana was assessed to determine its suitability for domestic use and irrigation activities. Stiff and Piper diagrams show that the predominant water type in the area is Na-Cl, which is characterized by relatively high salinities. This water type occurs in aquifers underlying six coastal districts, namely; Abura-Asebu-Kwamankese (AA), Mfantseman (MF), Gomoa East (GE), Awutu Senya (AwS), Effutu (EF) and Cape Coast (CC). Other water types are Ca-HCO₃, Ca-SO₄ and Ca-Cl, that occur in districts located further away from the coast. Silicate weathering and ion exchange are identified as the geochemical processes responsible for the various ions in the groundwater. Possible processes that could be responsible for the source of Na⁺ and Cl⁻ are sea water intrusion and dissolution of minerals. The results also show that the groundwater is mainly supersaturated with respect to both calcite and gypsum, indicating high concentrations of both bicarbonate and sulfate ions in solution. This is associated with considerable enrichment of the groundwater with sulfate, bicarbonate, and calcium ions. On a Wilcox diagram, the groundwater samples, mainly from the districts coded as AA, TLD, AS and AN, which are located away from the coast, plot within the “excellent to good” category, suggesting that water from the area is of acceptable quality for irrigation purposes. Similarly, Sodium Adsorption Ratio (SAR) and conductivity values for the groundwater in the AA, TLD, AS and AN districts indicate low SAR and low to medium salinity respectively. Groundwater in aquifers underlying these districts is therefore suitable for irrigation. Generally, groundwater samples from locations along the coast have high salinity and are not suitable for domestic and irrigation purposes. However, about 72% of the water samples predominantly in districts located away from the sea is suitable for the purposes stated.

Introduction

In many parts of Ghana the demand for water and subsequent abstraction for groundwater have increased in recent times. This is due partly to the seasonal and unreliable nature of surface water bodies, particularly rivers, especially during the dry season, when most small- to medium-size rivers dry up. In addition, most surface water bodies are susceptible to pollution, thereby

affecting the quality of the resource and the anticipated high cost of treating polluted surface water resources (Kortatsi, 2007). The pressure on groundwater resources is also attributed to the increased demand for domestic, agricultural and industrial use. Thus the welfare of every society is tied to the sustainable exploitation of water resources (Bear *et al.*, 1999).

In Ghana, sustainable national economic

development is tied to the proper development and management of groundwater resources in conjunction with surface water resources for use in households, agriculture and industry (Banoeng-Yakubo *et al.*, 2009). In Ghana, about 49% of the total population of 24.6 million people living in rural areas (Ghana Statistical Service, 2012), relies heavily on groundwater for their domestic and agricultural uses. Groundwater has therefore become the major source of potable water supply for most communities in Ghana. In the coastal regions in Ghana, notably the Western and Central Regions, and southern parts of the Volta Region (Kortatsi, 1994), the source of water for most irrigation schemes is groundwater from shallow aquifer systems. In the Keta basin of Ghana, a major problem associated with drinking water quality and management of domestic water supply is salinization of groundwater in hand-dug wells and in deep boreholes (Gill, 1969; Bannerman, 1994; Helstrup *et al.*, 2007).

In most of the areas where boreholes are sited, sanitary conditions around the wellhead are very poor, potentially leading to contamination from surface sources. However, the use of groundwater with elevated salinity levels has the tendency to reduce soil and crop productivity in such areas by destroying soil permeability and reducing the osmotic potential of crops. The high salinities of groundwater in some of the boreholes in the coastal areas of the Central Region and the potential use of the groundwater resource for irrigation purposes have necessitated an overall assessment of the quality of the resource in the area for domestic and irrigation activities.

Multivariate statistical analytical techniques have proven to be highly important in the handling, interpreting and graphically representing data with regards to groundwater hydrochemistry. Both factor and cluster analyses have been greatly adopted by several authors to appropriately constrain groundwater characteristics (Usunoff & Guzmán-Guzmán, 1989; Güler *et al.*, 2002; Liu *et al.*, 2003; Mahlknecht *et al.*, 2004; Kim *et al.*, 2005; Cloutier *et al.*, 2008; Yidana *et al.*, 2008; Tanaskovic *et al.*, 2012). Statistically, Q-mode hierarchical cluster analysis (HCA) and principal component analysis (PCA) were simultaneously applied to groundwater hydrochemical data by Belkhiri *et al.* (2011) in Algeria and revealed that the domain is characterized by three main hydrochemical facies. Again, Yidana *et al.* (2008) employed a multivariate statistical approach to identify the key process controlling the hydrochemistry of a basin in Ghana. This current study is of no exception to the use of geostatistical techniques in unravelling the hydrochemistry of the groundwater resources in the Central Region of Ghana.

This study therefore carried out comprehensive assessment of the quality of groundwater resources using multivariate statistical methods to determine its suitability for domestic and irrigation purposes in some parts of the Central Region of Ghana. The irrigation quality of groundwater in the study was assessed using conventional graphical methods, whereas the water quality parameters for domestic use were assessed using the standard conventional graphs.

The study area

Location

The study area covers 10 districts/municipal/metropolitan areas in the Central Region of Ghana (Fig. 1), bounded by longitudes $1^{\circ} 49' 53.868''$ W and $0^{\circ} 23' 59.586''$ W and latitudes $5^{\circ} 05' 48.484''$ N and $5^{\circ} 56' 23.525''$ N. The area represents about 70% of the region. The districts and municipalities are; Assin North (AN) Municipal, Assin South (AS) District, Cape Coast (CC) Metropolitan, Mfantseman (MF) Municipal, Effutu (EF) Municipal, Twifo-Heman Lower Denkyira (TLD) District, Abura-Asebu-Kwamankese (AA) District, Gomoa West (GW) District, Gomoa East (GE) District, and Awutu Senya (AwS) District (now divided into Awutu Senya District and Awutu Senya East Municipal). The study area lies within the dry equatorial climatic region, and falls within the evergreen and semi-deciduous forest zones. The area is characterized by two seasons, namely the dry and rainy seasons. The wettest months are May-June and September-October while the dry periods occur in December-February and a brief period in August. Mean monthly temperature ranges from 24°C in the coolest month of August to about 30°C in the hottest months of March/April. The mean annual rainfall ranges between 1000 mm and 2000 mm in the interior.

Geological and Hydrogeological Setting

The study area is underlain mainly by rocks of the Early Proterozoic Birimian in Ghana (Fig. 1) (Leube *et al.*, 1990), principally the Kibi-Winneba and Ashanti belts. Predominant among the rocks are the Cape Coast-type biotite granites/gneisses. Other rock types include volcanoclastics,

schists, amphibolites, an assemblage of sandstone, conglomerate and shale, as well as sediments, some of which form Mesozoic/Tertiary sedimentary basin along the coast of the Gulf of Guinea. All these rocks are crisscrossed by mafic dykes of predominantly doleritic composition.

Primary porosity and permeability is absent within the various rock types in the area. The availability of groundwater is strongly controlled solely by secondary porosity arising from weathering and development of secondary structures such as joints, shear zones, folds, fissures, faults and fractures. Depth of weathering is thicker in the sedimentary basin and volcanic belt compared to the crystalline basement rocks made of the granitoids (Ganyaglo *et al.*, 2012). Groundwater sometimes occurs in both the weathered zone and fractured fresh rock, and there are instances where water is obtained from only the weathered zone. Groundwater recharge takes place mainly by direct infiltration of rainfall and to a lesser extent from influence of streams and rivers (Ganyaglo *et al.*, 2012).

Methodology

Data for this study were compiled from various drilling projects coordinated and facilitated by the Community Water and Sanitation Agency (CWSA) in the Central Region of Ghana. A total of 102 borehole data were considered for all the parameters in this study, except Mn (92) and PO_4 (70). Under the project, groundwater samples were collected by experienced professionals, strictly adhering to standard groundwater sampling and analytical protocols. Samples were collected into 500

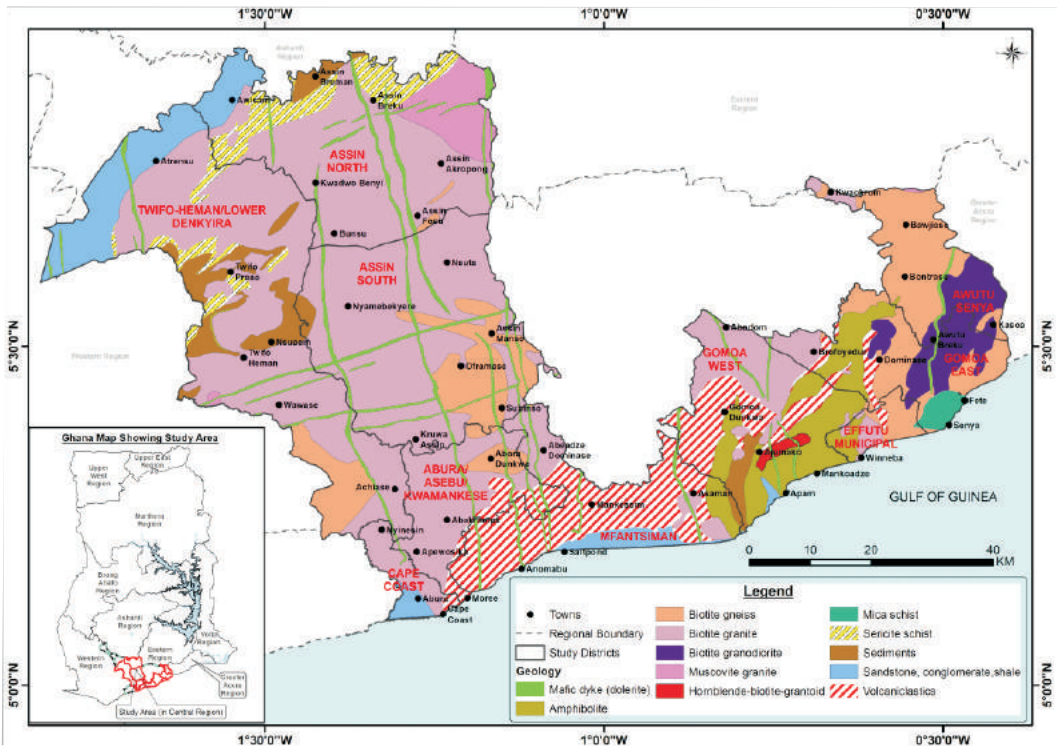


Fig. 1. Location and geological map of the study area showing the various districts and rocks distribution (Modified after GSD, 2009).

ml pre-sterilized polyethylene bottles. At each sample location, the sample bottles filled with water, were labeled; Cations, Anions and Silica. However, only a few samples were analyzed for silica, and therefore could not be used here.

The data collected in the field such as pH, Total Dissolve Solids (TDS), temperature, Electrical Conductivity (EC) were measured in-situ by using HQ40d18 series portable meter, whereas alkalinity was measured by means of titration against strong acid in the field. In the laboratory, the following anions and cations were determined; calcium (Ca^{2+}), sodium (Na^+), magnesium (Mg^{2+}), potassium (K^+), iron (Fe^{2+}), manganese (Mn^{2+}),

bicarbonate (HCO_3^-), fluoride (F^-), chloride (Cl^-), sulfate (SO_4^{2-}), and nitrate (NO_3^-). The major elements were measured in the laboratory of the Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR) in Accra. Prior to the laboratory analysis, samples for the major ions were preserved in line with the strict protocols spelt out in Appelo and Postma (2005). The major cations in the samples, namely Ca^{2+} , Mg^{2+} , Fe^{2+} and Mn^{2+} were analyzed using Atomic Absorption Spectrometry (AAS), whereas Na^+ and K^+ were determined using the flame photometer. Chloride (Cl^-) was analyzed by means of titration, whilst

nitrate (NO_3^-), phosphate (PO_4^{3-}), sulfate (SO_4^{2-}) were analyzed using Brucine reagent, Ascorbic Acid and Turbidimetric methods respectively and Ultra Violet Spectrometer. Fluoride (F^-) concentrations were obtained with the use of Hach Colorimeter.

Data for all the analyzed samples were subjected to internal consistency checks through the charge balance error (CBE) calculations using equation 1 (Appelo & Postma, 2005). As is consistent with standard practice, data from all the samples are required to be electrically balanced, which therefore requires that the CBE should not exceed the absolute value of $\pm 10\%$.

$$CBE = \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \times 100\% \quad \dots\dots\dots(1)$$

where the concentrations of the major anions and cations are in meq/l.

Spatial geostatistical analysis was conducted on the data obtained from the laboratory to aid in constraining the relationship between the available groundwater and its immediate environment. To achieve optimal multivariate geostatistical analytical results, the data was subjected to a check for normality and skewness (Usunoff & Guzmán Guzmán, 1989; Lambrakis *et al.*, 2004; Cloutier *et al.*, 2008; Belkhir *et al.*, 2011; Tanaskovic *et al.*, 2012). To this effect a normal descriptive statistical analysis was conducted using SPSS 22.0 on the data set to ascertain the validity of the data for geostatistical analysis. From the analysis, it was observed that apart from pH, Mn^{2+} and PO_4^{3-} which exhibited some level of normality, all the measured parameters exhibited different degrees of deviations from the normal (Table 1). In this light, all the data were subjected to log transformation

which is one of the most widely used transformation methods and standardization was conducted to decrease the variation from the mean value in order that the parameters appear alike in the distribution of their data.

An R-mode factor analysis was employed in this current study. Similarly, Principal Component Analysis (PCA) was used as the extraction method and the Kaiser (1960) criterion as the normalization index (Cloutier *et al.*, 2008). Equally, a varimax rotation matrix which functions as an orthogonal index to the factor matrix to heighten the differences between resulting factors for easy elucidation of the outcome was employed (Güler *et al.*, 2002; Cloutier *et al.*, 2008; Yidana *et al.*, 2008; Tanaskovic *et al.*, 2012). From the factor analysis, it was observed that PO_4^{3-} recorded a communality less than 0.50 and thus considered inconsequential, and subsequently taken out during the rest of the analysis. This was carried out to check the significance of each parameter to the overall outcome of the analysis. The Kaiser criterion was used to constrain the required number of factors which characterize the domain based on the available data. The Kaiser Criterion states that, a factor in the final factor model requires an eigen value of at least 1.0. This means that, a factor should be able to account for the variance of at least one parameter in the data set (Güler *et al.*, 2002; Cloutier *et al.*, 2008; Yidana *et al.*, 2008).

Sodium Absorption Ratio (SAR) is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of alkalinity/sodium hazard to crops. SAR for the data was computed using equation 2 as follows:

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

where the concentrations are in mmol/l. Irrigation waters having high SAR levels can lead to the build-up of high soil Na levels over time, which in turn can adversely affect soil infiltration and percolation rates. In addition excessive SAR can lead to soil crusting, poor seedling emergence, and poor aeration (Lesch & Suarez, 2009).

The sodium percentage (%Na) is widely utilized for evaluating the suitability of water quality for irrigation (Wilcox, 1948). Excess sodium concentration in groundwater produces the undesirable effects because Na reacts with soil to reduce its permeability and support little or no plant growth (Raju *et al.*, 2009; Vasanthavigar *et al.*, 2010). If the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing Mg^{2+} and Ca^{2+} ions. This exchange process in soil reduces the permeability and eventually results in deterioration of the soil structure and infiltration. Hence the circulation of air and water is restricted during wet conditions and such soils are usually hard when dry (Collins & Jenkins, 1996). The %Na for this study was calculated using equation 3:

$$Na\% = \frac{Na}{Na + Ca + Mg + K} \times 100 \dots\dots\dots(3)$$

where the concentrations of the individual species are expressed in meq/l

Results and discussions

Processes influencing the general hydrochemistry

A statistical summary of the physico-

chemical parameters analyzed in this study are presented in Table 1. The pH varies from an isolated 2.26 to 9.01 pH units, with a mean value of 6.34 and standard deviation of 0.762, indicating that the groundwater is predominantly acidic. The electrical conductivity (EC) ranges from a low value of 71.0 $\mu S/cm$ to 9760 $\mu S/cm$, yielding an average of $\sim 1773 \mu S/cm$. Generally, the high EC values occur along the coast, whereas the relatively low EC values occur in boreholes further inland. The total dissolved solids (TDS) concentrations range from 24.6 mg/l to 5,368 mg/l (Table 1). Groundwater with TDS values less than 1,000 mg/l has been described as fresh water whilst those with TDS values greater than 1,000 mg/l are classified as saline (Freeze & Cherry, 1979). The EC and TDS values suggest that groundwater in the area is predominantly fresh water, but saline water bodies are also present. Generally, boreholes along the coast recorded high concentrations of major cations such as Ca^{2+} , Mg^{2+} , K^+ , Na^+ , whereas boreholes located further inland have low concentrations of these cations. The order of abundance of these cations are $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$. Sodium ion (Na^+) ranges from 0.00 to 1,366 mg/l with a mean value of 120 mg/l, Ca^{2+} is 3.20-601 mg/l (averaged 57.9 mg/l), K^+ is between 0.0 and 80 mg/l, whereas Mg^{2+} varies from 0.90 mg/L to 374 mg/l. The anions also occur in the order $Cl^- > HCO_3^- > SO_4^{2-} > NO_3^- > F^-$. Cl^- ranges from 5 mg/l to 3216 mg/l, with a mean value of 274.6 mg/l, whilst HCO_3^- concentrations are 0.00–666 mg/l (averaged 133.6 mg/l). SO_4^{2-} varies from < 0.001 to 403 mg/l, whereas NO_3^- ranges from < 0.001 to 27.3 mg/l. The chemical parameters are

TABLE 1
Statistical summary (Descriptive Statistics) of the hydrochemical parameters in the study area

Parameter	N	Mean	Minimum	Maximum	Std. Deviation
pH	102	6.34	2.26	9.01	0.762
EC (mS/cm)	102	1117.79	71.00	9760.0	1773.19
TDS (mg/l)	102	645.17	24.60	5368.0	1030.79
TH (mg/l)	102	293.67	14.00	3040.0	514.74
Na ⁺ (mg/l)	102	120.02	0.00	1366.0	219.26
K ⁺ (mg/l)	102	11.55	0.00	80.0	13.99
Ca ²⁺ (mg/l)	102	57.91	3.20	601.0	96.20
Mg ²⁺ (mg/l)	102	37.45	0.90	374.0	75.86
Fe ²⁺ (mg/l)	102	0.458	<0.001	9.77	1.142
HCO ₃ ⁻ (mg/l)	102	133.58	0.00	666.0	103.89
SO ₄ ²⁻ (mg/l)	102	64.31	<0.001	403.0	92.75
Cl (mg/l)	102	274.61	5.00	3216.0	569.44
Mn ²⁺ (mg/l)	92	0.339	0.00	2.15	0.442
NO ₃ ⁻ (mg/l)	102	4.10	<0.001	27.3	5.32
F ⁻ (mg/l)	102	1.02	0.002	3.39	0.861
TA (mg/l)	102	112.30	20.0	546.0	86.78
PO ₄ ³⁻ (mg/l)	70	0.541	0.09	5.06	0.721

presented in Stiff (1951) diagrams in Fig. 2. The Stiff diagrams show the dominance of monovalent ions over divalent ions. It is obvious from Fig. 2 that six out of the ten districts, code-named AA, CC, MF, EF, AwS and GE, display identical shapes, with Na⁺+K⁺ ions being the dominant cations, whilst Cl⁻ is the predominant anion. Of the remaining four districts, Assin South (AS) and Twifo-Heman Lower Denkyira (TLD), have Ca²⁺ and HCO₃⁻ as the dominant cation and anion, respectively; Assin North (AN) has Ca²⁺ and SO₄²⁻ as the dominant ions, whereas Gomoa West (GW) is dominated by Ca²⁺ and Cl⁻.

Thus, the most predominant water type in the study area is Na-Cl. This water type occurs in aquifers underlying six district/municipal/metropolitan areas, namely; Abura-Asebu-Kwamankese (AA),

Cape Coast (CC), Mfantseman (MF), Effutu (EF), Awutu Senya (AwS) and Gomoa East (GE). All these districts are located along the coast with the exception of AA, which is located away from the coast but its proximity to the coastline explains why its underlying aquifer contains Na-Cl water type. From the coastal areas, the water type changes further inland towards the north and northwestern parts of the Central Region, into minor facies namely; Ca-Cl, Ca-HCO₃ and Ca-SO₄ in that order.

Piper (1944) diagram has been traditionally and most commonly used to classify water into different water types based upon the anion and cation concentrations in the form of major ion percentage. Piper plots are more useful in bringing out the chemical relationships amongst groundwater samples in more

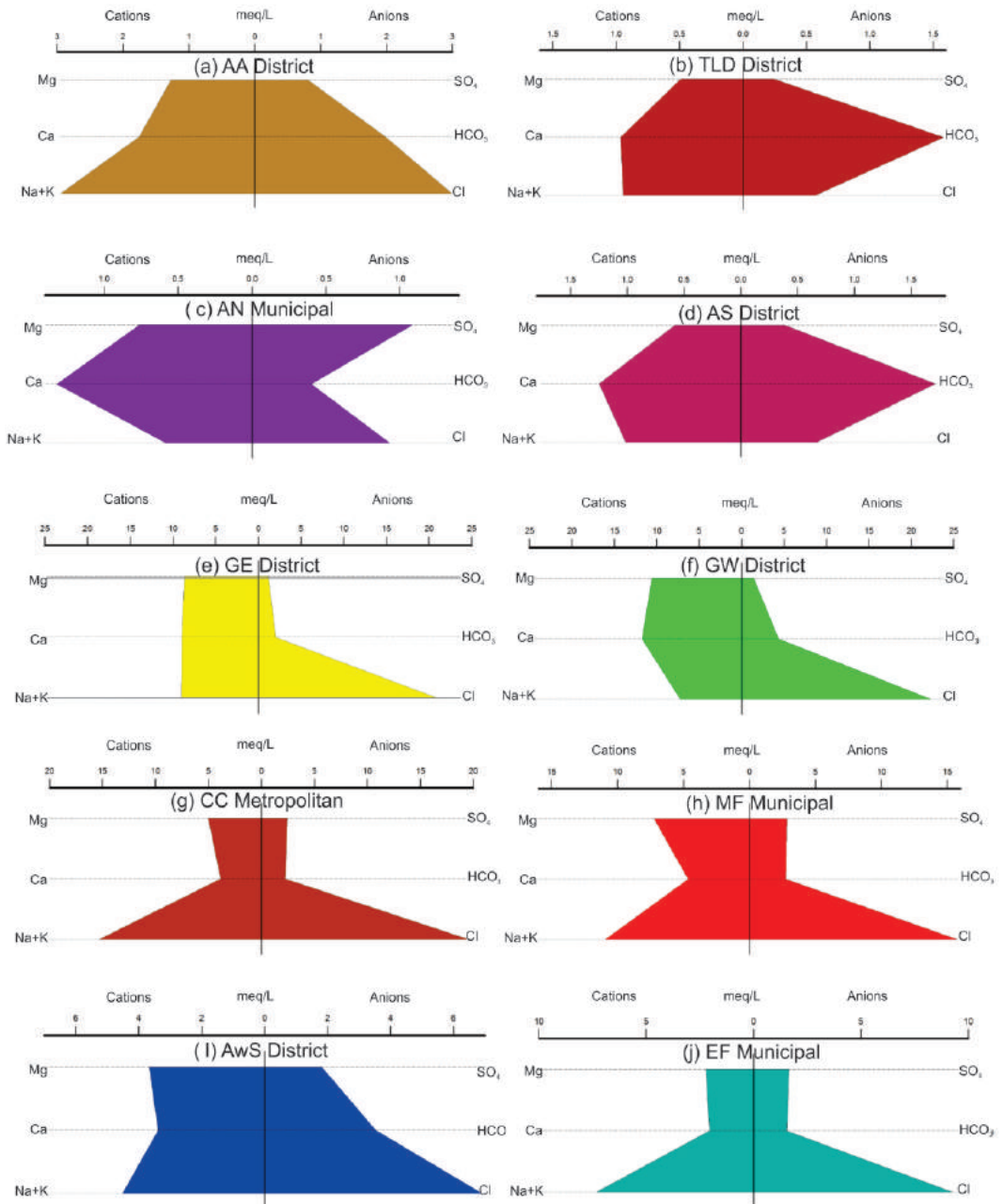


Fig. 2. Stiff (1951) diagrams for the average of the concentrations of the major ions in groundwater in the various districts. (a) Abura-Asebu-Kwamankese (AA) (b) Twifo-Heman Lower Denkyira (TLD), (c) Assin North (AN), (d) Assin South (AS), (e) Gomoa East (GE), (f) Gomoa West (GW), (g) Cape Coast (CC), (h) Mfantseman (MF), (i) Awutu Senya (AwS) and (j) Effutu (EF).

definite terms rather than with other possible plotting methods. In this study, the Piper diagram was used to further complement the classification of groundwater types as already established by the Stiff diagrams. Groundwater in AwS, AA, MF, EF, CC and to some extent GE display Na-Cl water type (Fig. 3a, b), with AS and TLD displaying Ca-HCO₃ water type (Fig. 3c). The water type for GW is not clearly defined because of the limited number of samples, however, a Ca-Cl (Fig. 3b) water type could be inferred for it. Similarly, that of AS is not clear, but a Ca-SO₄ (Fig. 3c) water type could be inferred for it. These classifications are similar to those observed on the Stiff diagrams. It is worth noting that, Ca-HCO₃ water type in Ghana is associated with areas where rock-water interactions are the major causes of variation in the hydrochemistry of groundwater (Yidana *et al.*, 2010; Ganyaglo *et al.*, 2012). And fresh groundwaters in coastal aquifers are dominated by the Ca-HCO₃ type waters resulting from the weathering of carbonate minerals and incongruent silicate mineral weathering (Drever, 1988; Appelo & Postma, 2005).

In the coastal areas of Ghana, high electrical conductivities are commonly attributed to seawater intrusion (SWI). However, according to Armah (2002), dissolution of minerals in the rocks could also give rise to salinization in the area. A preliminary study conducted by Ganyaglo *et al.* (2012) using 14 predominantly inland boreholes also concluded that NaCl in groundwater in the Central Region is concentrated in soil zone as a result of silicate weathering.

Water electrical conductivity (EC) is usually used as a salinity indicator. The

presence of dissolved salts in water is related to the value of its EC, as they provide electrical charges interacting as ions in movement. Chloride ions are the main constituents in waters and saline soils that directly affect the EC values; therefore, it is likely to establish a strong correlation between EC and Cl⁻ concentrations (Oteri, 1988; Hajrasuliha *et al.*, 1991; Xu & Eckstein, 1997; McNeil & Cox, 2000; Abyaneh *et al.*, 2005; Alhumoud *et al.*, 2010). In this study, the Cl⁻ ions display strong positive correlation with the EC (Fig. 4), suggesting increased salinity of the groundwater. Moreover, the chloride (Cl⁻) concentrations are relatively very high in boreholes in the coastal areas and could possibly be originating from sea water intrusion.

To further complement this observation, a 1:1 plot of Na⁺ against Cl⁻ in Fig. 5, akin to that proposed by Bear *et al.* (1999) was plotted to establish their ratio. The plot shows that some of the samples plot on the 1:1 equiline, thereby exhibiting Na⁺:Cl⁻ ratios equal to 1, whereas a few others plot above the equiline, displaying a ratio greater than 1. According to Rao (2008), ratio equal to 1 indicates the dissolution of NaCl, whilst ratio >1 implies a release of Na⁺ from silicate weathering. Many studies have used the Cl⁻ concentration in underground water to define the degree of saline intrusion. Some authors state that a threshold of chloride concentration ranging between 40 and 300 mg/l is an indication of seawater invasion (e.g., Edet & Okereke, 2001)

The geology of the study area, which is made up of about 85% crystalline basement rocks, notably granitoids, together with

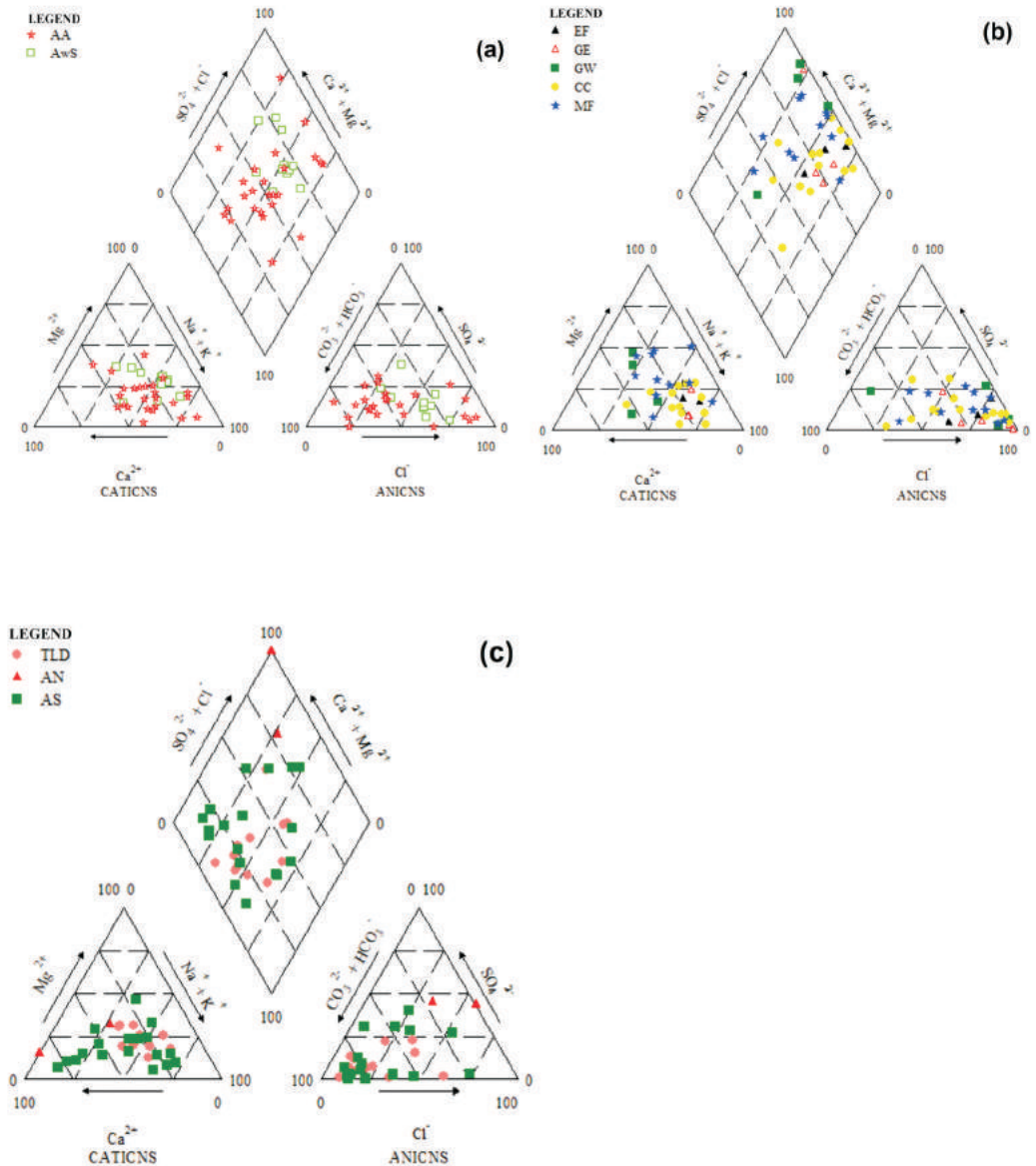


Fig. 3. Piper diagrams for the districts in the study area: (a) Abura-Asebu-Kwamankese (AA) and Awutu Senya (AwS); (b) Effutu (EF), Gomoa East (GE), Gomoa West (GW), Cape Coast (CC) and Mfantseman (MF); (c) Twifo-Heman Lower Denkyira (TLD), Assin North (AN) and Assin South (AS).

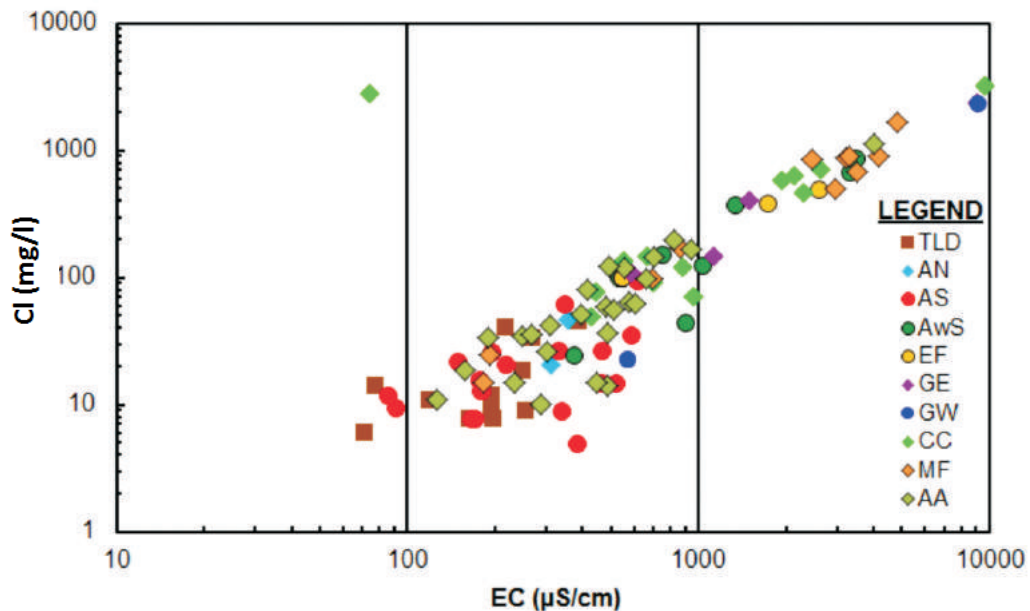


Fig. 4. Relation between Cl⁻ and EC in the Central Region groundwater.

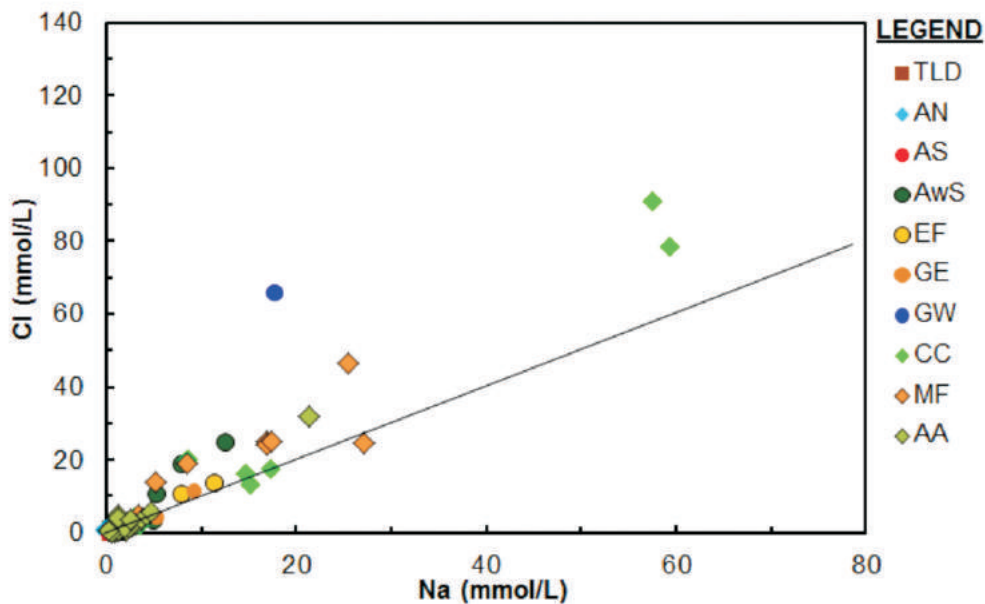
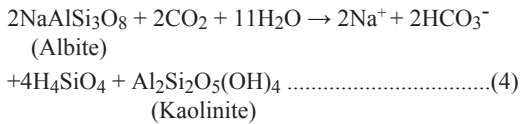


Fig. 5. Relation between Na⁺ and Cl⁻ in the Central Region groundwater. The solid line denotes 1:1 ratio.

schists, sandstones and some volcanic rocks, does not provide evidence of saline beds. However, almost all the boreholes with high Cl⁻ contents and high EC are located in the districts along the coast, whereas the those with low to moderately high Cl⁻ and EC values are in districts such as Assin North, Assin South and Twifo-Heman Lower Denkyira, located further inland. Based on these observations, it can be concluded that the NaCl in the groundwater can be attributed to sea water intrusion because of the proximity to the sea, and silicate weathering. In the underlying geology of the area, Na-rich feldspar (e.g., albite) is the dominant mineral, and the weathering of albite results in the release of Na⁺ (equation 4) into the soil zone that eventually finds its way into the aquifer.



This interpretation corroborates the findings of Ganyaglo *et al.* (2012) who further indicated that the source of Na⁺ in the aquifers could be attributed to the breakdown of albite, whereas the source of Cl⁻ may be from atmospheric input.

In the area, the Ca-HCO₃ water type occurs in Assin South (AS) and Twifo-Heman Lower Denkyira (TLD), and therefore may not have been affected by seawater intrusion, compared to the Na-Cl water types along the coast. Seawater is enriched in Na⁺ and Cl⁻ ions and therefore, groundwaters which are significantly influenced by seawater intrusion will inherit the hydrochemical signature of the seawater (Yidana *et al.*, 2010). However, where the freshwater was originally dominated by Ca²⁺

cations, the exchange sites will be dominated by this cation. Upon the intrusion of Na⁺ dominated seawater, cation exchange occurs in which case the originally Ca-HCO₃ freshwaters are gradually replaced by Ca-Cl waters. Incongruent weathering of albite and related plagioclase feldspars could potentially result in Ca-HCO₃ groundwater type in the study area. Possible processes that could be responsible for the source of Na⁺ and Cl⁻ and subsequently the salinization of the groundwater are sea water intrusion, dissolution of minerals and ion exchange.

Because most parts of the study area are located along the coast, with the occurrence of seawater intrusion and possible presence of saline beds in some locations, the salinities are expected to be high in some of the boreholes. This assertion can be clearly seen in factor 1 (Table 2) as Cl⁻ concentrations are loaded highest (0.965). Factor 1 explains about 47.262 % (Table 3) of the total variation in the geochemistry of the groundwater within the study area. It can clearly be seen that apart from Cl⁻, factor 1 also has high positive loadings for the major ions of Na⁺, Mg²⁺, Ca²⁺, K⁺ and SO₄²⁻. These elements are highly compatible in solution and could suggest a common source, possibly the underlying geology (Yidana *et al.*, 2008). The sources of Mg²⁺ in the groundwater could be due to the weathering of biotite (K(Mg,Fe)₃(AlSi₃)O₁₀(OH,F)₂) and hornblende (Ca,Na)₂₋₃(Mg,Fe,Al)₅(Al,Si)₈O₂₂(OH)₂ whereas Ca²⁺ could be leached from the weathering of calcic plagioclase feldspars such as andesine ((Ca,Na)(Al,Si)₄O₈) and oligoclase ((Ca,Na)(Si,Al)₄O₈), which are

TABLE 2
R-mode factor analysis of parameter loadings

<i>Parameters</i>	<i>Factor 1</i>	<i>Factor 2</i>	<i>Factor 3</i>	<i>Factor 4</i>
pH	.000	.284	.168	.668
EC (mS/cm)	.870	.275	.144	.042
TDS (mg/l)	.956	.178	.054	.020
TH (mg/l)	.884	.379	.138	.007
Na ⁺ (mg/l)	.913	.146	-.084	.048
K ⁺ (mg/l)	.511	-.036	.618	-.191
Ca ²⁺ (mg/l)	.781	.482	.147	-.004
Mg ²⁺ (mg/l)	.869	.281	.041	.031
Fe ²⁺ (mg/l)	-.125	.030	.718	-.014
HCO ₃ ⁻ (mg/l)	.301	.883	.180	.046
SO ₄ ²⁻ (mg/l)	.579	.131	-.304	-.036
Cl ⁻ (mg/l)	.965	.073	-.053	-.006
Mn ²⁺ (mg/l)	.197	.485	-.213	-.082
NO ₃ ⁻ (mg/l)	.035	-.293	-.075	.815
F ⁻ (mg/l)	.055	.149	.596	.337
TA (mg/l)	.333	.880	.185	.079

mineralogical components of the granitoids. Anorthite (CaAl₂Si₂O₈), another high-temperature calcic plagioclase feldspar is ruled out because, at high temperature, its occurrence in granitic rocks in the area is not likely. Other potential sources of Ca²⁺ and Na⁺ in the groundwater are weathered pyroxenes ((Na,Ca)(Mg,Fe,Al)(Al,Si)₂O₆) and hornblende. The source of the high SO₄²⁻ could possibly be from anthropogenic contamination such as farming. NO₃⁻ and SO₄²⁻ represents the contribution of agricultural chemicals to the hydrochemistry of these surface water basins. Nitrate- and sulfate-rich fertilizers and manures are extensively used in farming activities. The excess fertilizer is washed into the groundwater system, and this has the potential of raising the nitrate and sulfate levels beyond their natural concentrations. Equally, the high concentrations of these elements in solution could be contributing to

the observed high trend in TDS and EC values. The loadings of TH with respect to Ca²⁺ and Mg²⁺ are highly correlated since hardness of groundwater is solely due to the high occurrence of these elements in solution.

Factor 2 observes high loadings in pH, HCO₃⁻ and TA and contributes about 11.373% (Table 3) of the total variation in the hydrochemistry of the available groundwater resource. Acids are chemical compounds that produce H⁺ ions when dissolved in water. The stronger the acid, the more H⁺ ions they produce. Incongruent silicate mineral weathering, expedited by carbonic acid, indicates the production of the bicarbonate ion (HCO₃⁻) and cations in solution. The low pH characterizing the study area is indicative of abundant oxygen content and thus increasing the acidity of the medium, which is revealed in the high total alkalinity (TA) loading in factor 2. It

TABLE 3
Total variances explained by the various factors

Component	Initial eigen values			Extraction sums of squared loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1.	7.562	47.262	47.262	7.562	47.262	47.262	6.436	40.224	40.224
2.	1.820	11.373	58.635	1.820	11.373	58.635	2.586	16.163	56.387
3.	1.322	8.265	66.900	1.322	8.265	66.900	1.568	9.799	66.185
4.	1.169	7.303	74.204	1.169	7.303	74.204	1.283	8.018	74.204
5.	.942	5.888	80.092						
6.	.818	5.115	85.206						
7.	.664	4.149	89.356						
8.	.580	3.623	92.979						
9.	.455	2.845	95.823						
10.	.250	1.564	97.388						
11.	.188	1.177	98.564						
12.	.141	.880	99.444						
13.	.040	.248	99.692						
14.	.031	.192	99.885						
15.	.010	.063	99.947						
16.	.008	.053	100.000						

Extraction Method: Principal Component Analysis.

can therefore be deduced that carbonate mineral weathering is the main control in factor 2. Equally, it can be clearly seen that an increase in alkalinity would result in a contribution boost to the total percentage variance in factor 1, due to enrichment of HCO_3^-

Factor 3 (Table 3) accounts for about 8.265% of the total variation in the hydrogeochemistry of the groundwater with high loadings being observed in K^+ , Fe^{2+} and F^- . Again, these elements are highly compatible and suggest a common source, possibly the underlying geology (Appelo & Postma, 2005). These elements occur naturally in nature. K^+ in the groundwater could be attributed to the alteration of

plagioclase feldspar ($[\text{KAl}_2(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH},\text{F})]$) in the underlying geology into sericite. The high concentrations of Fe^{2+} as observed in some parts of the study area could not be attributed to anthropogenic activities, and as such the possible source being geogenic, through rock water interaction (Ganyaglo *et al.*, 2012). The geology of the study area is underlain mainly by biotite-bearing Cape Coast granitoids which occupy about 85% of the study area. The source of Fe^{2+} in the groundwater could be due to weathering of biotite ($\text{K}(\text{Mg},\text{Fe})_3\text{AlSi}_3\text{O}_{10}(\text{OH},\text{O},\text{F})_2$), and therefore, the observed high loadings of Fe^{2+} characterizing the domain. Fluoride concentrations range from 0.002 to 3.39

mg/l with an average concentration of 1.02 mg/l. Of the 102 boreholes investigated, 87 of them, representing ~85% have fluoride concentrations less than or equal to 1.50 mg/l, falling within the WHO (2003) permissible levels of 1.5 mg/l. The remaining 15 samples representing ~15% ranged between 1.537 to 3.39 mg/l fall outside the WHO standard for permissible drinking water (WHO, 2003). The intermediate to lower value range according to the above classification, occur in Cape Coast Municipality (CC), Abura-Asebu-Kwamankese District (AA) and Assin South District (AS), whilst the higher range values can be found in Gomoa East (GE), Assin South (AS) and Twifo-Heman-Lower Denkyira (TLD) Districts.

The moderately high fluoride levels (>1.5 mg/l) in the groundwater in about 15% of the boreholes is a major concern for the communities in these areas, since water with such concentration of F^- will cause skeletal and dental fluorosis when consumed. These areas are underlain predominantly by granitic intrusions, especially biotite granite. High fluoride levels have been recorded in groundwater in certain parts of the country. For example, in the Bongo District of the Upper East Region of Ghana, there are reported high levels of fluoride in groundwater (Apambire *et al.*, 1997), which are attributed to the dissolution of fluorite in groundwater in the Bongo granite. Recent geochemical and petrographic study of granitoids in the Bole-Nangodi belt by Sakyi *et al.* (unpublished), has also revealed the presence of fluorite in the rocks, thereby confirming the study of Apambire *et al.* (1997). The occurrence of high fluoride concentrations in limited areas of the study districts could be attributed to localized

occurrence of fluorine-bearing minerals such as fluorite (CaF_2), cryolite (Na_3AlF_6), and fluoroapatite ($Ca_5(PO_4)_3F$) that commonly occur as accessory minerals in the underlying granitoids rocks. Studies have also shown that biotite contributes up to 3400 ppm of fluoride in ground water (Deer *et al.*, 1992). The high fluoride concentrations in groundwater in metamorphic terrains are due to the dissolution of biotite, which may contain significant fluorine at the OH sites of their octahedral sheet (Dharmagunawardhana, 2004; Tainosho *et al.*, 2003; Nordstrom *et al.*, 1989). This is corroborated by the findings of Kularatne & Pitawala (2012) that showed that highly weathered biotite will readily leach high concentration of F^- into water percolating through the soil. Therefore the elevated F^- in some of the boreholes in the study area could be attributed to the weathering of biotite in the granitoids.

Factor 4, on the other hand, exhibits a high positive loading for pH and an equally high loading for NO_3^- , and contributing to about 7.303% (Table 3) of the total variation in the hydrochemistry of the groundwater. The loadings in factor 4 are attributable mainly to anthropogenic activities such as agriculture and improper disposal of waste. Nitrogen may also occur naturally in the soil in organic forms from the decay of plant and animal residues. The high loadings for NO_3^- and pH in factor 4 is therefore an indication that the concentration of NO_3^- contributes significantly to the low pH as observed in the study area.

Gibbs (1970) diagram was employed to adequately constrain the hydrochemical trends that characterize the study domain.

The diagram plots the total dissolved solids (TDS) on a logarithmic axis against the ratio of sodium and the sum of sodium and calcium on a linear axis, and is divided into zones based on the contribution of recharging precipitation, rock/mineral weathering and evaporation/crystallization on the hydrochemistry. The zonation is based on the ratio of the concentration of the Na⁺ ion to the sum of the concentrations of the Na⁺ and Ca²⁺ ions in the hydrochemistry plotted against the TDS content of the water under investigation. Waters that are affected by high evaporative effects are generally expected to display high TDS and Na/(Na+Ca) ratios, whereas those whose hydrochemistry is controlled primarily by mineral weathering processes, have moderate TDS and moderate Na/(Ca+Na). In addition, waters that are influenced mainly by the hydrochemistry of precipitation are characterized by low TDS and moderate to high Na/(Ca+Na) ratio. In Fig. 6, about 94% of the groundwater samples, spanning almost all the ten districts, plot within the “rock weathering” field. This suggests that rock dissolution is apparently the major process influencing groundwater hydrochemistry in the area, and this supports our earlier discussion on the prevailing processes and possible sources of the various ions.

Fig. 7 represents the stability diagram for the equilibrium relationship between calcite and gypsum for all the samples. In Fig. 7, all samples plot within the gypsum and calcite supersaturation field, suggesting the relatively high content of calcium in the system. It is apparent that groundwater in the aquifer underlying the study area is largely supersaturated with respect to both calcite

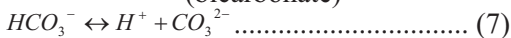
and gypsum, indicating high concentrations of both bicarbonate and sulfate ions in solution. This observed supersaturation of gypsum together with calcite is most likely associated with considerable enrichment of the groundwater with sulfate, bicarbonate, and calcium mainly through dissolution of minerals and subsequent reaction with other species. For the formation of calcite, as already discussed, the weathering of hornblende, plagioclase feldspar and pyroxene as well as hydrothermal alteration of the metavolcanics and metasediments could release Ca²⁺ into the groundwater. On the other hand, the reaction of infiltrating water and CO₂ produced through the decomposition of organic matter in the soil zone will generate HCO₃⁻ (Ganyaglo *et al.*, 2012), and this will eventually react with Ca²⁺ to form calcite. The equations below illustrate this;



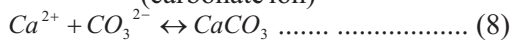
(carbonic acid)



(bicarbonate)



(carbonate ion)



(calcite)

The release of H⁺ could be responsible for the slightly acidic nature of the groundwater. In the absence of sea water intrusion that may influence the water type, the dissolution of the calcite could be responsible for the formation of the Ca-HCO₃ water type. Similarly, gypsum can be formed by the reaction of Ca²⁺, SO₄²⁻ and the groundwater. Possible sources of SO₄²⁻ are atmospheric input and the application of chemical fertilizers for farming activities in the region.

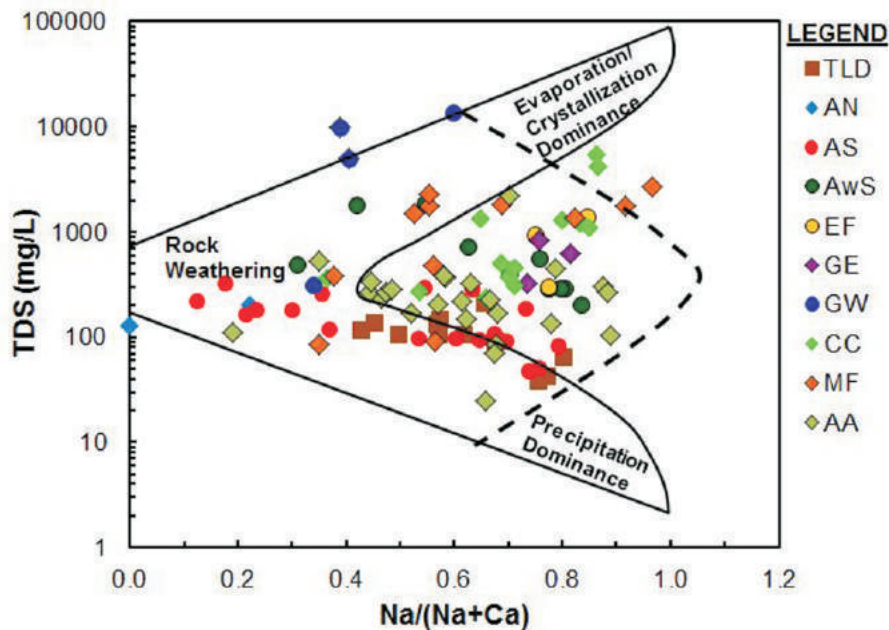


Fig. 6. Gibbs (1970) diagram showing the dominant source of variation in the groundwater hydrochemistry in the study area.

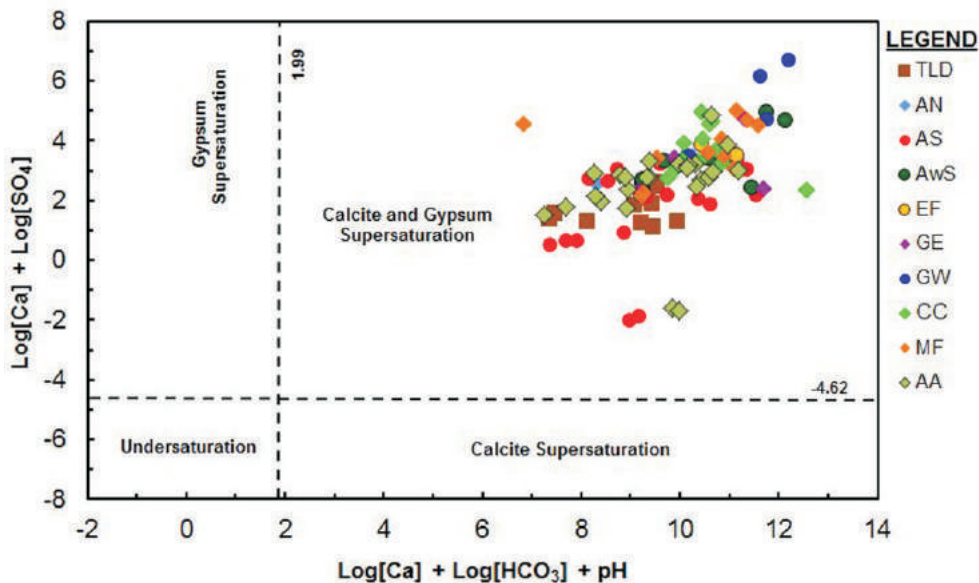


Fig. 7. The stability field for gypsum and calcite in the study area.

Suitability of groundwater for irrigation purposes

The assessment of the quality of water in the area for irrigation is based on the salinity and sodium content relative to the concentrations of the other major cations in the water system. Electrical conductivity is a good measure of salinity hazard to crops as it reflects the total dissolved solids in groundwater. Salinity hazard and sodium hazard are the important water quality issues, especially in irrigated areas (Jalali, 2007; Raju *et al.*, 2012). High salinity waters reduce the osmotic ability of plants and thus interfere with the capacity of plants to absorb water and nutrients from the soils and transport it to the branches and leaves (Saleh *et al.*, 1999; Jalali, 2007). This leads to a physiological drought of the plant although there may be a lot of water in the soil. This condition can cause the wilting of plants leading to death. In addition to the salinity effects, high concentrations of specific ions such as sodium, bicarbonate, and boron can be lethal to irrigation crops. Even if the salinity is low, high concentrations of these ions can interfere with the ability of plants to absorb water from soils. The long term effects of using high salinity waters for irrigation is the accumulation of salts in soils, leading to a reduction in the hydraulic properties of irrigation soils with time. When this happens, the ability of such soils to support optimum plant growth and development is greatly inhibited.

In this study, the Wilcox diagram (Wilcox, 1955) which plots the sodium percent against the EC was used to assess the quality of the four major groundwater classes in the study area for irrigation activities. The Wilcox (1955) diagram (Fig. 8) shows that most of the samples plot mainly within “excellent to

good” and marginally in “good to permissible” irrigation quality. This category excludes most of the samples from the coastal districts of EF, AwS, GE, MF and some samples from CC, which represent areas characterized by Na-Cl water types. Samples from the above-mentioned districts plot mainly across fields defined as “permissible to doubtful”, “doubtful to unsuitable” and ‘unsuitable’. This could possibly be due to the high salinity nature of groundwater samples from these districts, classified according to the water types. Consequently, they are not suitable for irrigation purposes. Instead, samples from districts located away from the coast, notably, AA, TLD, AS and to some extent, AN plot within “excellent to good” irrigation quality, and are therefore suitable for irrigation purposes. The generally low concentrations of the physico-chemical parameters in the groundwater in these districts is responsible for the low SAR and EC values, which have together influenced the irrigation quality of the groundwater in the area.

Fig. 9 presents the USSS (1954) diagram for the study area. Both the salinity and sodium content are generally low in the study area except a few other samples with high salinity and sodium content. Seventy three (73) samples, representing about 72%, plot within the C1-S1 and C2-S1 categories, representing low SAR and low to medium salinity. Samples within these two categories are mainly from AA, AS, AN, and TLD. Groundwaters from aquifers underlying these districts are interpreted to possess low SAR and low salinity and are therefore suitable for irrigation. The remaining 28% data points plot within

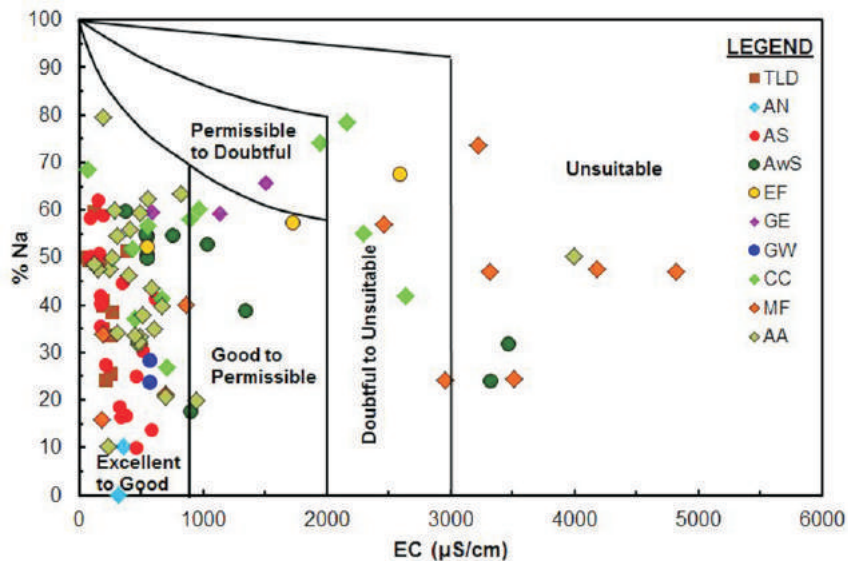


Fig. 8. Wilcox (1955) diagram used to assess the irrigation quality of groundwater in the study area.

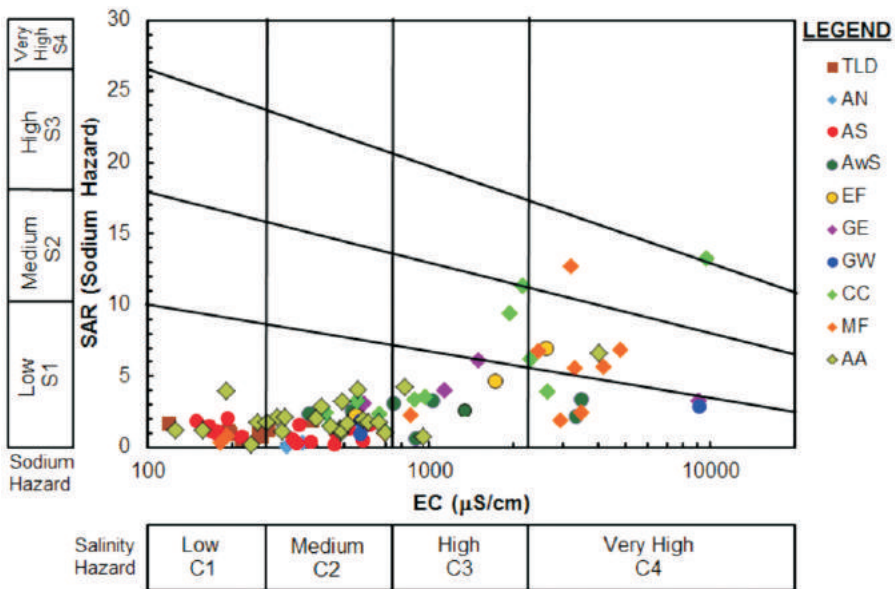


Fig. 9. USSL (1954) diagram for the assessment of the irrigation quality of groundwater in the study area.

other categories ranging from medium to very high SAR and high salinity. Samples in the very high SAR/salinity are mainly from districts coded as CC, MF, EF, AwS, and GE. These are districts mainly bounded by the Gulf of Guinea, and may have experienced seawater intrusion, resulting in high salinity and thereby rendering such water types unsuitable for irrigation purposes. This suggests that the use of water mainly from the coastal districts in the Central Region of Ghana is likely to pose sodium or salinity effects. This is however dependent on the conditions of the soils, whereby poor drainage can lead to the retention of salts in the soil zone, thus leading to the accumulation of salts in these soils over the long term. On the contrary, in the districts located away from the coastal areas, the water quality is suitable for the intended purpose.

Conclusion

Groundwater samples from ten districts in the Central Region of Ghana were analyzed and assessed to determine the suitability of the groundwater for domestic and irrigation purposes. Here, we make the following conclusions from our results; Groundwater in the area is weakly acidic with average acidity of 6.34 pH units. TDS ranges from 24.6 to 5368 mg/l, while the EC varies from 71 to 9760 $\mu\text{S}/\text{cm}$. Both EC and TDS values decrease from the coast toward inland, and suggest that groundwater in the area is predominantly fresh water, but saline water bodies also exist.

The order of abundance of the cations are $\text{Na}^+ > \text{Ca}^{2+} > \text{K}^+ > \text{Mg}^{2+}$, while that of the anions are $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{F}^-$. One major and three minor hydrochemical facies have been identified, namely; Na-Cl,

which is the dominant water type, and Ca-Cl, Ca- HCO_3 and Ca- SO_4 . In the order stated the water type changes from the coastal areas towards the north and northwestern parts of the region. The Na-Cl water type occurs in aquifers underlying the six coastal districts, namely; Abura-Asebu-Kwamankese (AA), Cape Coast (CC), Mfantseman (MF), Effutu (EF), Awutu Senya (AwS) and Gomoa East (GE). Assin South (AS) and Twifo-Heman Lower Denkyira (TLD) have Ca- HCO_3 water type, Assin North (AN) has Ca- SO_4 , whereas Gomoa West (GW) is characterized by Ca-Cl facies.

Silicate weathering and ion exchange are identified as the predominant geochemical processes responsible for the various ions in the groundwater. Possible processes that could be responsible for the source of Na^+ and Cl^- are sea water intrusion and dissolution of minerals.

Generally, groundwater underlying districts coded as AA, TLD, AS and AN, that are located away from the coast, plot within the "excellent to good" category, suggesting that water from the area is of acceptable quality for irrigation purposes. The remaining districts are underlain by groundwater of variable qualities. Similarly, SAR and conductivity values for the groundwater from the same districts indicate low SAR and low to medium salinity, suggesting that the water in these districts is suitable for both domestic and irrigational purposes.

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