Multidimensional assessment of groundwater quality in some communities of the lower PRA basin of Ghana

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ABSTRACT

Multidimensional assessments of groundwater quality have been carried out in some communities of the Lower Pra Basin in Ghana. Samples were collected from thirty one (31) water points. All ions were determined using standard methods. Results show that ion concentrations are primarily influenced by various hydrogeological processes such as silicate weathering, ion exchange and sea aerosol spray. From the SAR calculation, 90.3% of the water was within the excellent category; 6.5% and 3.2% were within the good and unsuitable category respectively. Calculation of % sodium showed 7%, 48%, 32% and 13% being good, permissible, doubtful and unsuitable respectively. From the Wilcox's diagram, approximately 71% fall within excellent to good category; 26% in the category of permissible to doubtful; 3% within the doubtful to unsuitable category. Approximately 90% of the samples were found to be good by RSC index; 7% fall within the doubtful category and 3% unsuitable. A high percentage was within permissible ranges for TDS and TH. The results suggest that generally groundwater samples are suitable for domestic and irrigation purposes under normal temperature and pH condition.

Introduction

It is estimated that approximately one third of the world's population use groundwater for drinking (UNEP, 1999). In Ghana, groundwater is increasingly gaining prominence as an alternative source of water for various uses. A number of reasons account for this: aquifers underlie almost all communities in Ghana and can be tapped at relatively shallow depths; groundwater is relatively cleaner and does not need extensive treatment before use; most surface water bodies run out during the dry season (Yidana, 2009). In Ghana, the purpose of groundwater use is largely determined by the quantity of groundwater available, its quality and the unavailability of other alternatives (Kortatsi, 1994). Boreholes in almost all regions, with the exception of the Greater Accra regions are exclusively used to supply water for drinking and other domestic purposes (Kortatsi, 1994). Groundwater has become an important source of potable water for most communities in the lower Pra Basin since the mining activities within the Pra Basin has rendered most surface waters polluted and the cost of water treatment highly prohibitive. The dependence on groundwater for domestic and other purposes in the Lower Pra Basin justifies a research into the quality of groundwater for various purposes. The data was subjected to multivariate analytical techniques using Statistical Package for Social Sciences (SPSS) software (Version16.0). These techniques help to simplify and organize the data in order to make useful generalizations (Kumar et al, 2008).

The study area

The climate of the study area falls mainly within the Wet Semi-equatorial climate. There are two rainfall maxima, but the mean annual rainfall is between about 125 and 200 centimetres. The first rainy season is from May to June, with the heaviest rainfall in june.

The second rainy season is from September to October (Benneh and Dickson, 2004). Temperatures are almost the same as in the south-west equatorial region (26°C in August and 30°C between March and April). Monthly relative humidity is higher in the rainy seasons than during the rest of the year. The highest average monthly humidity does not exceed 75% and the lowest is about 60% (Benneh and Dickson, 2004).The study area is within the coastal plain. The land is not flat but rather undulating. Various types of rock are found here, but the most widespread are the granites which also form most of the hills. The coastline is different from that of the south-east coastal plains and forms a series of bays and headlands, and is cliffed in numerous places (Benneh and Dickson, 2004).

Geology of the study area

The lower Pra basin is characterized primarily by Cape Coast granitoid complex, Discove granotide complex and Upper Birimian. The bulk of the Cape Coast granite complex is a granitic to quartz dioritic gneiss, which in the field is seen to change gradually from fine to medium grained, foliated biotite quartz diorite gneiss to exclusively hornblende-guartz-diorite gneiss. Amphibolites, hornblendites and basic hornblende gneisses occur. The gneissic rocks are intruded by both acidic and basic igneous rocks, which include white and pink pegmatite, aplites granodiorites and dykes (Ahmed et al., 1977). Discove granotide complex consist of hornblende granite or granodiorite grading locally into quartz diorite and hornblende diorite, sometimes believed to have been formed from gabbros by magmatic differentiation (Kesse, 1985). The Upper Birimian Series consists of great thickness of basaltic and andesitic lavas,

beds of agglomerate, tuff and tuffaceous sediments (Kesse, 1985).

The Upper Birimian is, therefore, of volcanic origin. The basic volcanic and pyroclastics have been altered largely to chloritized and epidotised rocks that have been loosely grouped together as greenstones. Where the greenstones have been subjected to dynamothermal metamorphism, they have been converted to hornblende schists and amphibolites. Close to granitoid complexes, these schists and amphibolites grade with the addition of feldspars, into hornblende gneisses (Kesse, 1985).

Materials and methods

Samples were collected from thirty one (31) water points (boreholes and hand-dug wells). Sampling protocols described by Claasen(1982) and Barcelona et al(1985) were strictly followed during sample collection: the sampling bottles were conditioned by washing with detergent, then with ten percent (10%) nitric acid, and finally rinsing several times with distilled water. This was carried out to ensure that the sample bottles were free from contamination, which could affect the concentrations of various ions in the groundwater samples. At the sampling points, the boreholes were pumped for five minutes to purge the aquifer of stagnant water so as to acquire fresh samples for analysis. Samples were collected in duplicate, and samples earmarked for metal analysis were acidified to a pH less than 2 after filtration using reagent grade nitric acid. Samples for anion analysis were without preservation because addition of acids could lead to a reaction with the carbonates in the water sample. `Samples for cation analysis were filtered on site through 0.45μm filters on acetate cellulose into 250ml bottles and immediately acidified to a pH less than 2 by addition of Merck TH Ultra pure nitric acid. Samples for anion analysis were collected into 600cm^3 polyethylene bottles without preservation.

All samples were stored in an ice-chest and transported to the Ghana Atomic Energy Commission chemistry laboratory, stored at temperature less than four degrees Celsius (4^{0}C) and analysed in ten days. The physical parameters and major ions were determined using standard methods (APHA, 1998). Fig. 1 shows the location and geological map of the study area.
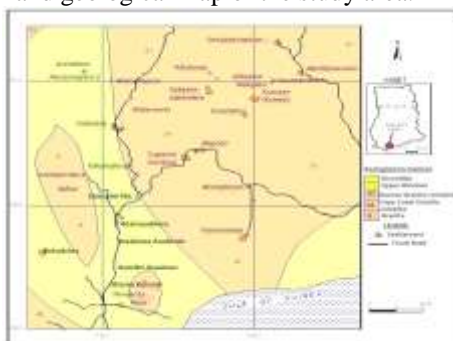

Fig. 1 Location and geological map of the study area

Results and discussion

Principal component analysis (PCA), as stated by Harman (1976) gives a simple interpretation for a given data and affords an elemental description of a certain set of variables analysed. In the hydrochemistry field, these techniques are widely used because they have several advantages over traditional graphical approaches (Dalton and Upchurch 1978). The number of components to keep was based on the Kaiser criterion, for which only the components with eigenvalues greater than 1 are retained (StatSoft Inc., 2004). Four components were extracted. The four

components, therefore, have eigen values > 1. The extracted components explain approximately 82.3% of the variability in the original 15 variables. As shown in the scree plot (figure 2) the eigen value sharply decrease within the first four components and then slowly stabilize for the remaining ones.
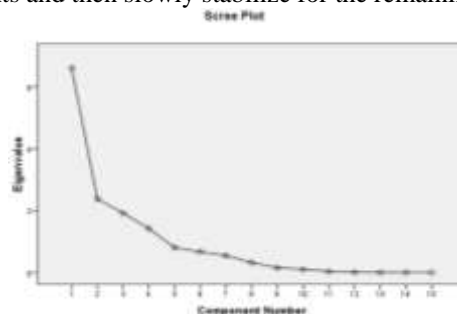

Figure 2: Scree Plot Showing Eigen Values Against Component Numbers

Electrical conductivity (EC), Salinity, Sodium (Na$^+$), Chloride(Cl$^-$), Sulphate (SO$_4^{2-}$) show high positive loading (0.814 – 0.973). The concentration of Nitrate (NO$_3^-$) and temperature have moderate positive loading (0.568-0.687) in the first component. The second component contain high positive loading of Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and hardness (.696-0.912). The third component is governed by bicarbonate (HCO$_3^-$), total dissolved solids (TDS) and phosphate (PO$_4^{3-}$) (.555-0.792) whereas fourth component exhibit calcium (Ca^{2+}) and phosphate (PO$_4^{3-}$) (Table 1).

On the basis of this component loading, the first component can be established as "salt factor" as it contains EC and some important inorganic salts together with salinity. The first component is associated with a combination of various hydrogeochemical processes that contribute to enrich ions. These ions are primarily by silicate weathering, ion exchange processes and sea aerosol spray. This is evident in the approximately 74% of the water samples having Na$^+$/ (Na$^+$ + Cl$^-$) ratio within the range of 0.5 ± 0.1 or a plot along or close to 1:1 line of the Na$^+$ vrs. Cl$^-$ gragh, implying that sea aerosol spray is partially responsible for Na$^+$ and Cl$^-$ in the groundwater (there is no evidence of halite in the basin) (Figure 3a); Gibbs plot (figure 3b) indicating a high percentage of rock dissolution. A plot of Na-Cl against Ca+Mg-(HCO$_3$+SO$_4$) gives a slope of -0.634 (figure 3c), showing some level of ion exchange.
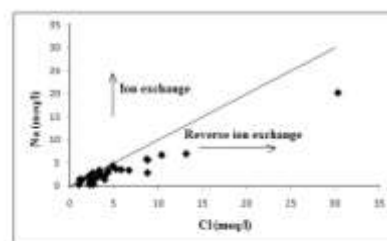

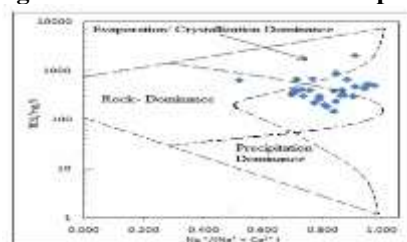**Figure 3a: Na$^+$ and Cl$^-$ relationship**

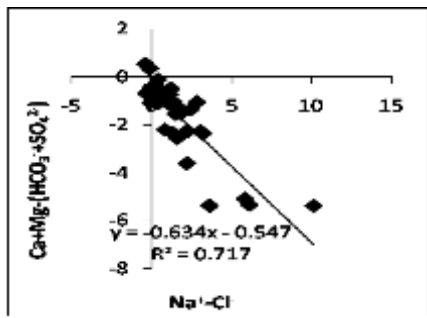**Figure 3b: Mechanism governing groundwater chemistry**

Figure 3c: Relationship between $Ca^{2+}+Mg^{2+}-(HCO_3^-+SO_4^{2-})$ And Na^+-Cl^-

The loading of Ca^{2+}, Mg^{2+} and hardness which is an obvious situation hardness being influenced mainly by Ca^{2+}, Mg^{2+} can be attributed to evaporate minerals gypsum (hydrous calcium sulphate=$CaSO_4.2H_2O$), and the anhydride ($CaSO_4$). The third component accounts for 12.816% of the total variance and reveals HCO_3^- contribute high percentage of the total dissolved solids in the basin. The carbonate may be explained by water-rock interactions. Recharge water increases its reactivity as it infiltrates the soil through the uptake of CO_2 produced from decaying organic matter. The CO_2 in water forms H_2CO_3 which acidifies the circulating ground waters. This acidity is subsequently neutralized by the cation release from weathering and ion exchange process by the aquifer materials which could also be partly attributed to component four.

Suitability for irrigation
Alkalinity Hazard

The sodium/alkali hazard is typically expressed as the sodium adsorption ratio (SAR).This index expresses the proportion of sodium (Na) to calcium (Ca) and magnesium (Mg) ions in a sample. Sodium hazard of irrigation water can be well estimated by determining the SAR. The SAR value for each water sample was calculated by using the following equation (Richard, 1954):

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

Where the concentrations are reported in meq/l.

From the SAR calculation, 90.3% of the water was within the excellent category; 6.5% and 3.2% were within the good and unsuitable category respectively (figure 4).
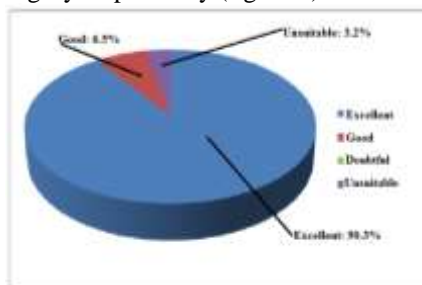

Figure 4: Irrigation water quality based on SAR

In this study, the sodium adsorption ratio, SAR, which measures the proportion of sodium relative to the combined concentrations of calcium and magnesium, and the salinity as measured by the electrical conductivity, EC, were also used to construct the United States Salinity Laboratory's diagram (USSL, 1954) (Figure 5) for groundwater from the Lower Pra Basin of Ghana. A very high percentage of the samples fall within the S1 and C1 portions of the diagram. These

groundwaters are, therefore, generally useful for irrigation without prior dilution with low salinity waters. A few samples, however, fall within the high category and will, therefore require dilution with low salinity water.
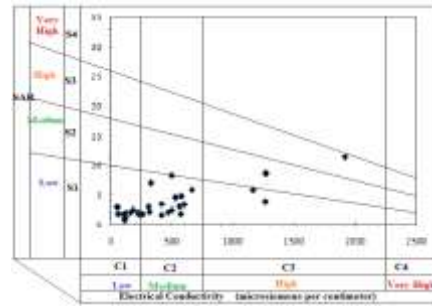

Figure 5: Irrigation water classification for groundwater for groundwater in the Lower Pra Basin Sodium Percentage (Na %)

Percent sodium (%Na^+) is also widely utilized for evaluating the suitability of water quality for irrigation (Wilcox 1948). The %Na^+ is computed with respect to relative proportions of cations present in water, where the concentrations of ions are expressed in meq/l, using the following formula:

$$\% Na = \frac{Na+K}{Ca+Mg+Na+K} \times 100$$

Excess Na^+, combining with carbonate, leads to formation of alkaline soils, whereas with Cl^- saline soils are formed. Neither soil will support plant growth (Rao, 2006). Calculation of % sodium showed 7%, 48%, 32% and 13% being good, permissible, doubtful and unsuitable respectively.
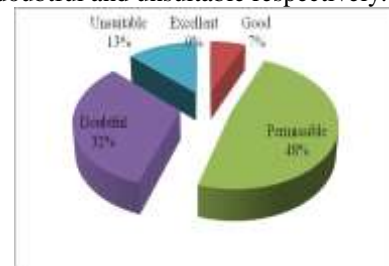

Figure 6: Irrigation water quality based on percent sodium

The percent sodium was plotted against EC in the Wilcox Diagram (Wilcox 1948) which is adopted for the classification of groundwaters for irrigation. From the Wilcox's diagram (Figure 7), approximately 71% fall within excellent to good category; 26% in the category of permissible to doubtful; 3% within the doubtful to unsuitable category.
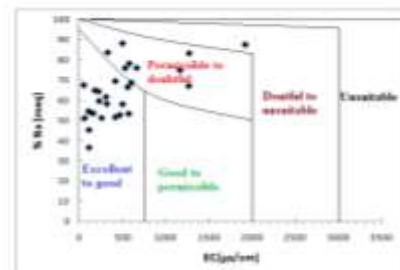

Figure 7: Rating of groundwater samples on the Wilcox Diagram

Bicarbonate Hazard

Bicarbonate hazard is usually expressed in terms of RSC (Residual Sodium Carbonate). RSC is calculated using the following equation:

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

In waters having high concentration of bicarbonates, there is tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. As a result, the relative proportion of sodium in the water is increased in the form of sodium bicarbonate (Sadashivaiah et al, 2008). Residual carbonate levels less than 1.25 epm are considered safe. Waters with RSC of 1.25-2.50 epm are within the marginal range. The continues use of waters having RSC more than 2.5 meq/l leads to salt build up which may hinder the air and water movement by clogging the soil pores, leading to degradation of the physical condition of soil. RSC (2.5-4) can be used effectively with the addition of gypsum. Sodic soils could be used with gypsum addition and green manuring (Latha et al, 2002). Approximately 90% of the samples were found to be good by RSC index; 7% fall within the doubtful category and 3% unsuitable (figure 8).
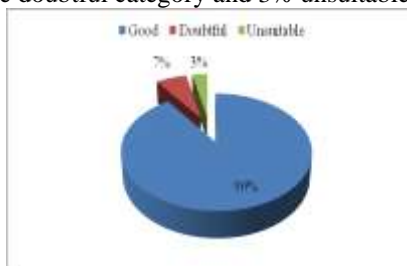
Figure 8: Irrigation water quality based on RSC

Total Hardness (TH) and Total Dissolved Solids (TDS)

Total hardness varies between 63 to 106 mg/l. Maximum allowable limit of TH for drinking water is specified as 500, and the most desirable limit is 100, as recommended by WHO standard. The total hardness of the sample ranged between 55.9 mg/l and 165 mg/l. The mean, median and standard deviation values are 104.9 mg/l, 101.9mg/l and 32.2mg/l respectively as depicted by the radar plot in figure 9.

The range and standard deviation shows that there is considerable high variation in the total hardness. Also, the mean and median values show most of the values are within 100 to 105, which falls within the moderately hard classification of water hardness.
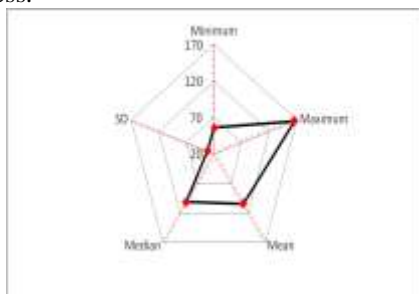
Figure 9: Radar plot for TH

TDS index basically assesses the water quality based on salinity hazard (Carmelita et al, 2010). Water with TDS up to 1000m/l is considered as fresh; water with TDS value between 1000 mg/l and 3000 mg/l is considered slightly saline; from 3000mg/l-10000 mg/l is moderately saline and 10000 mg/l-35000 mg/l is highly saline. From the analysis of groundwater in the Lower Pra Basin, minimum and maximum values are 146 mg/l and 2030 mg/l respectively. The mean, median and standard deviation values are respectively 507.8 mg/l, 394.5 mg/l and 425.3 mg/l (figure 10).
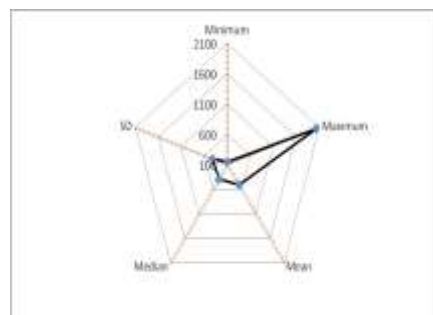
Figure 10: Radar plot for TDS

Although there high standard deviation showing variation in the study area, most sample fall below the 1000 mg/l mark for fresh water. Only one sample, representing a percentage of approximately 3, have TDS value of 2030, which shows slightly saline water.

Conclusion

From the SAR calculation, 90.3% of the water was within the excellent category; 6.5% and 3.2% were within the good and unsuitable category respectively. Calculation of % sodium showed 7%, 48%, 32% and 13% being good, permissible, doubtful and unsuitable respectively. From the Wilcox's diagram, approximately 71% fall within excellent to good category; 26% in the category of permissible to doubtful; 3% within the doubtful to unsuitable category. Approximately 90% of the samples were found to be good by RSC index; 7% fall within the doubtful category and 3% unsuitable.

The results suggest that the groundwater samples are suitable for irrigation purposes under normal Temperature and pH condition. A few samples, however, fall within the high category and will, therefore require dilution with low salinity water before used for irrigation. From the analysis of groundwater in the Lower Pra Basin, minimum and maximum TDS values are 146 mg/l and 2030 mg/l respectively. The mean, median and standard deviation values are respectively 507.8 mg/l, 394.5 mg/l and 425.3. Only one borehole had TDS value greater 1000 mg/l, representing approximately 3%. Approximately 97% of the water samples have TDS values lower than 1000mg/l. The water in the basin is, therefore, generally fresh. Also, the mean and median values for total hardness show that most of the values are within 100 to 105, which falls within the moderately hard classification of water hardness.

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