Hydro chemical Characterization and Assessment of Groundwater Suitability for Drinking, Domestic and Irrigation Purposes in the Agona East District, Ghana

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Abstract- ***The groundwater quality in the Agona East District has been evaluated for drinking and irrigation uses. Fourteen boreholes from the district were sampled and analyzed to study the groundwater hydrochemical characterization. The objective was to characterized groundwater chemistry on a small scale to understand the processes that influence the hydrochemistry of the groundwater, the possible source of contaminates and the groundwater suitability for drinking and agricultural purposes. Previous studies have reported on the hydrochemical characterization of groundwater on a large scale. However, the detail work with regard to groundwater characterization as well as the quality of the groundwater in the locality is lacking.***

The study involves taken of groundwater samples, analysis of the samples in the laboratory and analysis of the data generated. The order of the cation in the water samples is $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$ ***while that of the anions is*** $HCO_3^{-} > SO_4^{2-} > Cl^{-} > NO_3^{-}$***. The study revealed that the major groundwater types in the study area are CaMgCHO3, mixed water and NaCl in decreasing order. The study identified carbonates weathering, silicate weathering, ion exchange together with improper waste disposal as factors influencing the hydrochemistry of the area. The high correlation between groundwater parameters indicates that similar processes influence the concentrations of the parameters. The groundwater is considered suitable for drinking and domestic purposes because almost all the parameters such as*** Na^{+}, K^{+}, HCO_3^{-}, Cl^{-} ***are within the permissible limits prescribed by WHO (2012), and calculation of WQI shows that it is good for drinking purpose. However, low pH is the health-based concern observed in the groundwater use for drinking and domestic purposes. The groundwater is generally good for irrigation; however, the high sodium percent (%Na > 60%), high Kelly Index (KI > 1) and High Magnesium Ratio (MR > 50%) in some samples are the concern observed for the groundwater use for irrigation.***

Indexed Terms- ***Agona East, Groundwater, Water quality index, Irrigation***

I. INTRODUCTION

One of the essential natural resources needed for the socio-economic development of a country is water. Clean drinking water promotes good hygiene and improved health. The socio-economic activities include industrial and commercial activities, navigation, transportation, hydroelectric power generation, and agricultural activities. Groundwater serves as a source of drinking water in many parts of the world because unlike surface water, groundwater usually needs no or little treatment to be fit for drinking purposes (WHO, 2006), hence, groundwater resources need to be protected against contamination in order to avoid water-related diseases. The study conducted by European Environment Agency (EEA) and United Nations Economic Commission for Europe (UNECE) in 1999 showed that most people around the world depend on groundwater as a source of drinking water (EEA, 1999; UNECE, 1999). In Ghana, groundwater is mainly used for drinking, domestic and irrigation purposes since there is no supply of treated water in villages and small towns, unlike the urban cities where Ghana Water Company Limited supplies treated water (Gyau-Boakye et al., 2008). The increase in demand for groundwater in Ghana can be partly attributed to the contamination of the surface water bodies by anthropogenic activities such as illegal mining locally referred to as

"Galamsey". The availability of water and its quality is essential for public health, agriculture, and industry (Vanloon and Duffy, 2005). Recently, the use of groundwater for drinking, domestic and irrigation has increased globally (Hynds et al., 2014). This has caused a lot of research to be made on the relationship between groundwater use and its effects on public health. However, some of these studies have shown that groundwater is prone to contaminants such as waterborne pathogens, toxic elements (Asamoah and Amorin, 2011). In fact, of late water resource has become one of the most important environmental issues due to contamination from both geogenic and anthropogenic sources (Ghasemi et al., 2011). Some of the parameters dissolved in water are good for human health when within a certain range of concentration whiles others are harmful (Raju, 2007; Wang, 2013). WHO identified that about 80% of all death in developing countries are related to the consumption of contaminated water (WHO, 2002).

The quality assessment of groundwater from the study area is very important because it serves as source water for all their water needs. In fact, every borehole drilling project includes an initial assessment of the groundwater based on parameters of health significance prior to the groundwater use. However, this is not enough the interaction between the rock minerals as well as the impacts of anthropogenic activities have the potency to alter the chemical composition of the groundwater with time and compromise its quality. Therefore, it is essential to continually monitor the quality of water for human consumption. This will help in the early detection of any changes in the water quality and mitigate any epidemic that may result from contaminated groundwater. In view of this fact, an evaluation of the quality of the groundwater based on the Water Quality Index (Couillard and Lefebre, 1985; Yogendra and Puttaiah, 2008) has been made for drinking and domestic use. Also, since the users also use the water for irrigation, the suitability of the groundwater has been assessed by Wilcox diagram (Wilcox, 1955), Residual Sodium Carbonate (RSC) (Raghunath, 1987), Permeability Index (PI) (Doneen, 1964), Kelly Index (KI) (Narsimha, 2013) and Magnesium Ratio (MR) (Paliwal, 1972)

II. STUDY AREA

Agona East District has a high population density of 159 per sq. km. The District is located between latitudes 5^{o} 30' N and 5^{o} 50' N, and longitudes 0^{o} 35' W and 0^{o} 55' W (Fig. 1). It lies within a wet semi-climatic regime, which is characterized by two wet seasons of unequal intensity of rainfall (Dickson & Benneh, 2004). Annual rainfall intensity ranges between 1200 - 1500 mm with the mean annual temperature of about 27^{o}C.

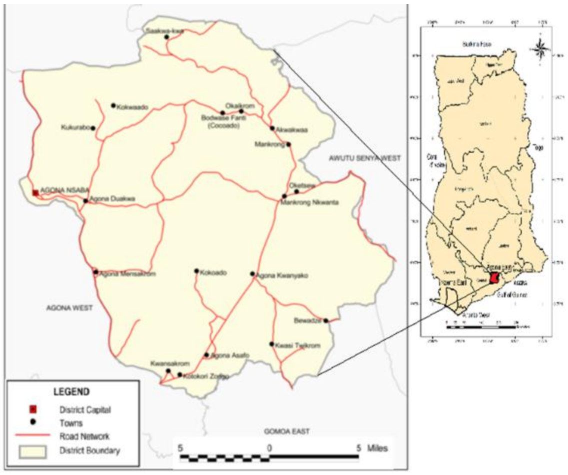


Fig.1 Map of Agona East District (Ghana Statistical Report, 2010)

The first rainfall season begins from May to June with the peak occurring within July. The second rainy period is from September to October. The vegetation cover is of the moist-semi deciduous forest type. Here the trees exhibit deciduous habit. Thus, most of the trees do not shed all their leaves during the long dry periods of the year (November – March) when the influence of harmattan is very relatively pronounced. Annual evapotranspiration conditions ranged between 1450 – 1500 mm. The study area is primarily underlain by Ebunean plutonic suite. This formation is associated with Granitoid gneiss, biotite gneiss (GSD, 2009). The area lies within a geologic contact Tamnean Plutonic Suite. The proximity of the area to geologic contacts, fractures could be enhanced to facilitate groundwater accumulation. Also, there are a lot of fractures prevailing within the area. This could be attributed to geologic tectonic activities (Kesse, 1985).The District is drained predominantly by the Ayensu river. Two other rivers, Ochi-Amissah and Ochi-Narkwa also drain sections of the districts. Borehole drilling success in the granitic terrains of the Region may generally be as high as 75% (Dapaah-Siakwan & Gyau-Boakye, 2000).

III. METHODOLOGY

The study involved the sampling of fourteen boreholes from the study area for physical and chemical analysis. The physical parameters [pH, Total Dissolved Solids (TDS) and Electrical Conductivity (EC)] were measured of the field during sampling by following the WHO (2008), and American Public Health Association (APHA, 1995) regulations and procedures. The samples were kept in ice chest containing ice packs and sent the Laboratory for further analysis by employing the standard methods (APHA, 1995). Probe method was used to measure temperature, pH, conductivity, and TDS. Ion chromatography was used to analyse fluoride, chloride, sulphide, nitrate, bromide, phosphate, carbonate, silicate and sulphate. Flame Atomic Absorption Spectrometry (AAS) was used to analyse copper, manganese, cadmium, magnesium, calcium, zinc and iron. The bicarbonate which was expressed in terms of alkalinity ($CaCO_3$ mg/l) was converted into HCO_3^- by using the formula proposed by Hem (1985). Total suspended solids (TSS), total hardness (TH), alkalinity, turbidity, colour, salinity while sodium and potassium were analysed by photometric method 8006 (Non filterable residue), titrimetric method, titration method, absorptiometric method, cobalt standard method, electrical conductivity method, and flame photometer respectively. Duplication of three samples with different codes and computation of ionic balance for the samples were used the assess the accuracy of the laboratory results (Celesceri et al., 1998).

IV. RESULTS AND DISCUSSION

Parameter	Unit	Minimum	Maximum	Mean	Std. Deviation	Variance	WHO (2012)
TDS	Mg/l	124.96	932.00	497.07	184.62	34080.00	1500.00
Cl^-	Mg/l	12.50	380.00	127.14	93.08	8663.00	250.00
HCO_3^-	Mg/l	70.76	334.28	187.35	76.90	5914.00	300
SO_4^{2-}	Mg/l	1.00	44.00	14.21	14.99	224.64	250.00
NO_3^-	Mg/l	0.00	0.20	0.03	0.05	0.00	50.00
Ca^{2+}	Mg/l	6.00	80.00	51.57	22.19	492.42	75.00
Na^+	Mg/l	8.11	246.62	78.31	59.22	3507.00	200.00
Mg^{2+}	Mg/l	4.86	46.17	20.62	11.52	132.82	150.00
K^+	Mg/l	0.00	62.00	14.33	15.28	233.50	30.00
Ph	pH Unit	6.00	7.06	6.44	0.33	0.11	6.50-8.50
EC	Us/cm	248.71	1935.67	1026.50	385.90	148900.00	1000.00
Col#	PCU	0.00	5.00	2.04	1.45	2.10	15.00
SiO_2	Mg/l	6.00	36.00	14.86	12.64	159.67	
Turb#	Mg/l	0.00	14.90	3.16	3.72	13.81	5.00
Alkal#	Mg/l	58.00	274.00	151.86	63.80	4070.00	
TH	Mg/l	40.00	430.00	238.57	101.06	10210.00	500.00

CO_3^{2-}	Mg/l	0.00	0.00	0.00	0.00	0.00	300
F^-	Mg/l	0.00	0.65	0.22	0.21	0.04	1.5
Fe	Mg/l	0.00	0.70	0.10	0.19	0.04	0.30
NH_4^+	Mg/l	0.00	0.35	0.09	0.10	0.01	

Table1 Statistical summary of the groundwater data

Table 1 shows pH mean value of 6.44 and a range of 6.00-7.06. 57% of the total samples have pH values less than the permissible range of 6.50 to 8.50. The increase of acidity of groundwater increases its ability to dissolve different substances such as heavy metals (Chotpantarat et al. 2014). Therefore, the pH will have an influence on the levels of metals in the groundwater. This can render the water unfit for drinking sometimes as the concentration of dissolved substances increases (WHO, 2012).

The EC values range from 248.71µS/cm to 1935.67µS/cm with a mean of 1026.50 µS/cm which is higher than the WHO (2012) limit for potable water supply (1000 µS/cm). The high EC values of the groundwater suggest that the area serves as a discharge area of the aquifers involved and therefore receives water that flows from the recharge area through the rocks. The high EC values indicate the occurrence of solute dissolution through rock-water interactions (Oyem et al., 2014). The TDS of the groundwater samples are all below the recommended limit of 1500mg/l (124.96.00 – 932.00 mg/l). This observation can be attributed to the short residence time which prevents the water from reacting with the host rock to attain equilibrium or due to possible low rate of weathering of rocks in the study area (Kortatsi, 2004). The moderate TDS values also suggest that the hydrochemistry of the groundwater is mainly controlled by natural processes instead of anthropogenic activities.

The statistical summary of the groundwater data is presented in Table 1. The order of the cations in the water samples is seen as $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ while that of the anions is seen as $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-$. The concentrations of Ca^{2+} are within the range of 6.00-88.00 mg/l and the sources may include dissolution of rock minerals such as pyroxene, calcite and/or ion exchange processes through rock-water interaction. Excess of calcium contributes to water hardness. However, calcium is an essential element that promotes human health by strengthening bones and teeth as well as the reduction of incidence of heart disease (Sengupta 2013). The range of Mg^{2+}concentration in the groundwater is 4.86-51.03 mg/l which is below the recommended value of WHO (2012). The low concentrations of Mg^{2+} can be attributed to the low degree of dissolution of these minerals and/or ion exchange processes through rock-water interaction.

The range of HCO_3^- concentration is 70.76-334.28 mg/l which may be influenced by the dissolution of carbonate rocks such as limestone and dolomite and CO_2 (Karanth, 1989). The concentration SO_4^{2-} in the groundwater ranges from 4.00 mg/l to 54.00 mg/l and the sources may include dissolution of gypsum ($CaSO.2H_2O$), oxidation of sulphide bearing minerals such as pyrite (FeS_2) and arsenopyrite (FeAsS) or by anthropogenic activities such application of agrochemical and improper waste disposal. The dissolution of iron and manganese-bearing minerals such as pyrite, and iron-rich clay minerals like amphiboles, pyroxenes and biotite increase the iron concentration in groundwater (WHO, 1996). The concentrations of Fe are within the range of 0-0.70 mg/l. According to Grazuleviciene et al. (2009), although Fe is an essential element, a higher concentration in drinking water can lead to health issues such as gastrointestinal upset, nausea, vomiting and constipation. They observed that, in severe cases, Fe toxicity can cause organ damage, coma or even death. Studies show that F^- concentration above 0.6 mg/L in drinking water could lead to a reduction in tooth decay children, however, consumption of water with F^- concentration above 1.5 mg/L leads to dental fluorosis and skeletal fluorosis (Kumar and Puri 2012). F^-concentrations are generally low (0-0.65 mg/l). The sources of NO_3^-

in groundwater may include runoff of inorganic fertilizers from farmlands as well as human and/or animal excreta that may leach into the groundwater (Chindo et al. 2013). Studies show that a high level of NO_3^- in drinking water can lead to methemoglobinemia in infants. Also, NO_3^- can also be converted to NO_2^- which can react with organic compounds to produce possible carcinogenic N-nitroso compounds in the stomach after ingestion (Xu et al. 2015). The range of NO_3^- concentration in the groundwater is 0-0.20 mg/l which is below the recommended value of 50 mg/l. the concentration of NH_4^+ ranges from 0 to 0.35 mg/l while that of magnesium ranges from 4.85mg/l to 51.03 mg/l.

V. CORRELATION STUDY

Table 2 Pearson correlation coefficient matrix for parameters in groundwater samples

Parameters	TDS	Cl-	HCO_3^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Na^+	Mg^{2+}	K^+	Ph	EC	Col#	SiO_2	Turb#	Alkal#	TH	F^-	Fe	NH_4^+
TDS	1																		
Cl^-	.764**	1																	
HCO_3^-	.537*	-0.127	1																
SO_4^{2-}	0.124	-0.295	0.506	1															
NO_3^-	-0.014	0.21	-0.256	-0.181	1														
Ca^{2+}	.818**	0.423	.702**	0.156	-0.098	1													
Na^+	.790**	.982**	-0.073	-0.245	0.047	0.439	1												
Mg^{2+}	0.444	0.064	.622*	.561*	0.334	0.336	0.033	1											
K^+	0.014	-0.397	0.529	0.069	-0.274	0.222	-0.364	-0.072	1										
Ph	0.302	-0.344	.912**	0.471	-0.332	.607*	-0.295	0.404	.655*	1									
EC	1.000**	.764**	.537*	0.124	-0.014	.818**	.790**	0.444	0.014	0.302	1								

Col#	-0.122	-0.31	0.227	-0.119	-0.391	0.274	-0.288	-0.321	0.355	0.49	-0.122	1							
SiO_2	-0.116	-0.062	-0.085	-0.209	0.216	0.219	-0.117	-0.169	-0.133	0.142	-0.116	.652*	1						
Turb#	-0.173	-0.16	-0.092	-0.065	-0.22	0.184	-0.136	-0.494	0.045	0.151	-0.173	.740**	.678**	1					
Alkal#	0.507	-0.142	.983**	0.498	-0.149	.671**	-0.111	.673**	0.506	.903**	0.507	0.184	-0.078	-0.167	1				
TH	.684**	0.439	0.515	0.153	.557*	.693**	0.353	.744**	-0.09	0.319	.684**	-0.178	0.156	-0.235	.573*	1			
F^-	0.154	-0.052	0.319	-0.071	0.111	0.177	-0.048	0.196	0.425	0.128	0.154	-0.396	-0.396	-0.467	0.294	0.241	1		
Fe	0.224	-0.259	.658*	.717**	-0.089	0.392	-0.232	.601*	0.152	.537*	0.224	-0.025	-0.154	-0.071	.660*	0.387	0.142	1	
NH_4^+	0.18	0.092	0.101	0.306	-0.02	0.154	0.124	0.22	-0.064	-0.058	0.18	-0.351	-0.179	-0.25	0.071	0.142	0.333	.573*	1

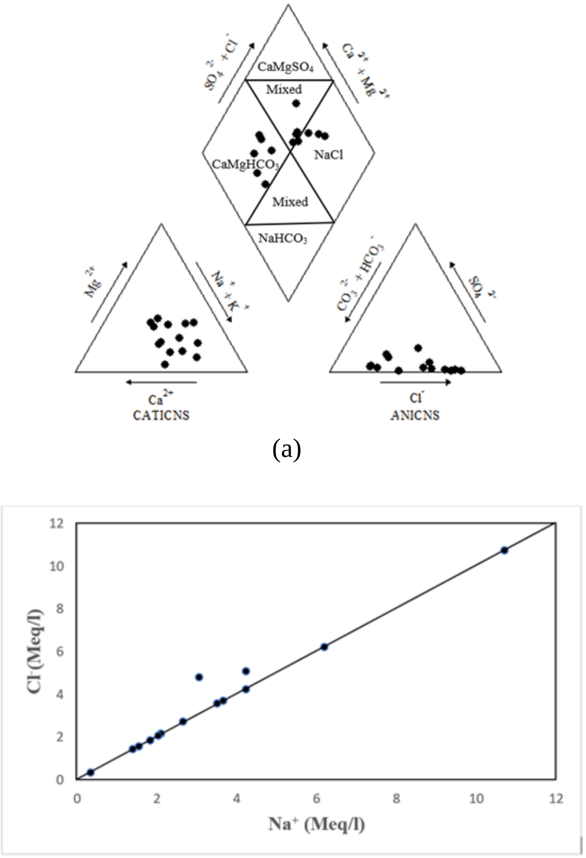
The relationships between the various parameters were identified by Pearson's correlation matrix (Table 2). Correlation between SO42- and Mg2+ (0.561), HCO3- (0.506) as well as the correlation between Fe and HCO3- (0.658), SO42- (0.717), alkalinity (0.660) and NH4+ (0.573) and Mg2+ (0.601) indicate the influence of anthropogenic activities on the hydrochemistry of the groundwater in the study area.

The strong positive correlation between SiO2 and colour (0.652), turbidity (0.678) shows that silicate weathering influences the colour and the turbidity of the groundwater in the study area. The correlation between alkalinity and HCO3- (0.983), Ca2+ (0.671), Mg2+ (0.673) shows that the alkalinity of the water samples is controlled by carbonate weathering. The correlation between EC and Cl- (0.764), Na+ (0.790), Alkalinity (0.507), Ca2+ (0.818), HCO3- (0.537) shows effect of carbonate weathering on the EC. Strong correlation between pH and HCO3- (0.912), alkalinity (0.903), Fe (0.537), Ca2+ (0.607) as well as the correlation between HCO3- and Mg2+ (0.622), Ca2+ (0.702), show that concentration of pH is influenced by Carbonate weathering. The TDS strongly correlated with the Cl- (0.764), Na+ (0.790), EC (1.000), TH (0.684), alkalinity (0.507), HCO3- (0.537) and Ca2+ (0.818). The high concentrations of the TDS which strongly correlate with TDS, Cl-, Na+, EC, TH, alkalinity and Ca2+ indicate that dissolution of rock minerals controls the TDS in the groundwater. The groundwater total hardness (TH) shows a strong correlation with Ca2+ (0.693) and

Mg2+ (0.744), alkalinity (0.573), HCO3- (0.515), NO3- (0.557), EC (0.684), which reflects that they originated from the same sources. Potassium concentration correlates with HCO3- (0.529), pH (0.655), alkalinity (0.506).

VI. HYDROCHEMICAL FACIES OF GROUNDWATER

The plot of major ions on the Piper diagram (Piper, 1944) diagram reveals that $CaMgHCO_3$ (or $CaCHCO_3$), NaCl and mixed water types are the major water types in the study area. The Ca^{2+} and HCO_3^- derived from the weathering of minerals in the bedrock, including calcite. About, 43% of the groundwater samples were characterized as $CaHCO_3$ water type. According to Narany et al., (2014), this water type may have resulted from the occurrence of carbonate dissolution process. The low concentrations of Na^+ in the $CaHCO_3$ water type indicate that little cation exchange and dissolution of Na-minerals has occurred. The groundwater type changed to mixed water type and then to NaCl along the flow path. Equal concentrations of Na^+ and Cl^- enter into groundwater during halite dissolution, therefore, a linear relationship may be observed between the two ions when plotted on a bi-plot (Hem, 1985). The plots of Na^+ vs. Cl^- concentrations fall on the equiline when halite dissolution influences groundwater chemistry. The plot of Cl^- vs Na^+ in Figure 2b indicates that there is defined linear relationship between the two parameters which indicates that the concentrations of the two parameters are influenced by the same process such dissolution of halite or sea water intrusion. Mixing of various water types plays a major role the study area. Mixed water types have no single ion that shows dominance; hence, they do not have any specific feature that is particular to them. The mixed water could result from weathering of different minerals and/or mixing of two chemically distinct groundwater types.



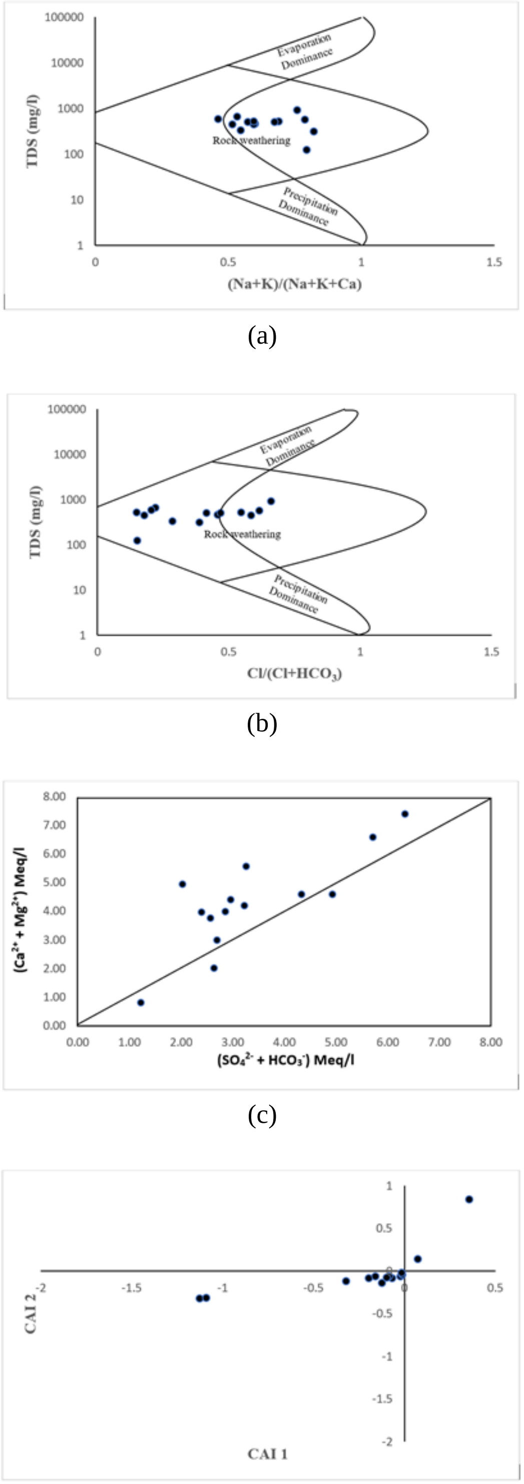
(a)

(b)

Fig. 2: (a) Piper (1944) diagram showing the relative cation and anion composition of groundwater samples and (b) a plot of Cl^- against Na^+.

VII. HYDROGEOLOGICAL PROCESSES

The Gibbs diagram (Gibbs, 1970) (Fig. 3 a, b) was used to further highlight the evolutionary trends and the possible sources of variation in groundwater hydrochemistry in the area. The diagram is divided into regions based on contribution from atmospheric precipitation which are characterised by low to moderate TDS and high $(Na^++K^+)/(Na^++K^++Ca^{2+})$ weight ratio, rock dominance region; exemplified by moderate TDS and $(Na^++K^+)/(Na^++K^++Ca^{2+})$ ratio and an evaporation-crystallization region; typically in the high TDS and $(Na^++K^+)/(Na^++K^++Ca^{2+})$ ratio.



(a)

(b)

(c)

(d)

Fig 3: a) A plot of TDS vs. Na^++K^+/ (Na^++K+Ca^{2+})b) A plot of TDS vs. Cl^-/ (Cl^-+HCO_3^-)) c) A plot of (Ca^{2+}+Mg^{2+}) vs. (SO_4^{2-}+HCO_3^-)d) A plot of CAI 1 vs. CAI 2 of groundwater of the study area.

A similar observation was shown by Cl^-/(Cl^-+HCO_3^-). The plot of Gibbs diagrams indicates that rock weathering is the major factor controlling the groundwater hydrochemistry. A bivariate plot of (Ca^{2+}+Mg^{2+}) and (SO_4^{2-} + HCO_3^-) suggests that carbonate weathering, silicate weathering and ion exchange are hydrogeochemical processes that contribute to the hydrochemistry of the groundwater. Figure 4c reveals that carbonate weathering is the major rock weathering process that influences the hydrochemistry of the groundwater system since the majority of the samples plot above the 1:1 equiline (Tiwari and Singh, 2014). Weathering of carbonates may be accounting for excess Ca^{2+}+Mg^{2+} in the samples that plot above the equiline (Tiwari and Singh, 2014). The increase in the concentration of Ca^{2+} + Mg^{2+} in the groundwater may be attributed to the dissolution of pyroxene anorthite plagioclase, amphibole and calcite, biotite, augite, and hornblende. Again, the increase in the concentration of Ca^{2+} + Mg^{2+} in the groundwater may be due to interaction between atmospheric water charged with CO_2 with the rock materials which further results in the formation of carbonic acid and increases the rate of the dissolution of carbonate minerals such as limestone.

However, the excess SO_4^{2-} + HCO_3^- ions in the samples that plot below the equiline (as shown by few samples in fig 4c) could result from silicate mineral weathering or ion exchange processes. The silicate weathering produces secondary minerals such as clays like kaolinite, and iron oxides due to the insolubility of Al-compounds (Appelo and Postma, 2005). The effect of silicate weathering on the groundwater hydrochemistry is the addition of cation and silica into the groundwater. A plot of samples on the equiline (Ca^{2+} + Mg^{2+} = SO_4^{2-} + HCO_3^-) may indicate the weathering of carbonate and sulphate minerals that are present in the rocks of the study area. However, carbonate weathering appears to be the principal hydrochemical process in the groundwater system of the study area since the majority of the samples plot above the 1:1 equiline.

Chloro-alkaline indices were used in this study to further understand the process of ion exchange between the host rocks and the groundwater.

According to Schoeller (1965), CAI 1 and CAI 2 are calculated by the following equations;

$$\mathrm{CAI\ 1} = \frac{\mathrm{Cl} - (\mathrm{Na} + \mathrm{K})}{\mathrm{Cl}} \qquad (2)$$

$$\mathrm{CAI\ 2} = \frac{\mathrm{Cl} - (\mathrm{Na} + \mathrm{K})}{\mathrm{SO_4} + \mathrm{HCO_3} + \mathrm{CO_3} + \mathrm{NO_3}} \qquad (3)$$

Where values are measured in meq/l.

The plot of CAI 1 and CAI 2 (eqn. 2& 3) shows that the majority of the samples show negative indices which indicate that ion exchange of Mg^{2+} or Ca^{2+} in groundwater with Na^{+} and K^{+} in the host rock (Schoeller, 1965) takes place through rock-water interaction in the study area. The few samples that show positive indices indicate the occurrence of reverse ion exchange where Na^{+} and K^{+} in groundwater exchange with Mg^{2+} or Ca^{2+} in the host rock. This means that ion exchange process affects the groundwater geochemistry in the study area.

VIII. SUITABILITY OF GROUNDWATER FOR DRINKING, DOMESTIC AND IRRIGATION PURPOSES

The assessment of suitability for drinking purpose was evaluated by water quality index (WQI) by following the steps reported by Couillard and Lefebre (1985). The calculations of WQI are based on the standards suggested for uses, where eleven groundwater quality parameters (pH, TH, Ca^{2+}, Mg^{2+}, HCO_3^{-}, Cl^{-}, TDS, F^{-}, NO_3^{-}, SO_4^{2-} and Fe) are considered. In the first step, weights (wi) are assigned to measured parameters based on their relative importance in the overall water quality for drinking purposes and possible health effects (Table 4). The highest weight of 5 was given to NO3- which is considered to have significant effects on human health through drinking water.

In the second step relative weights (Wi) are calculated using the following equation.

$$\mathrm{W_i} = \frac{\mathrm{w_i}}{\sum_{i=1}^{n} \mathrm{w_i}} \qquad (4)$$

Where Wi= relative weight, wi= assigned weight and n=number of parameters

In step three equation (5) was used;

$$\mathrm{q_i} = 100 * \left(\frac{\mathrm{C_i}}{\mathrm{S_i}}\right) \qquad (5)$$

Where Qi=quality rating, Si=WHO (2012) value in mg/l and Ci=concentration from laboratory in mg/l

In the fifth step sub-index (SI) is calculated for each parameter using;

$$\mathrm{SI_i} = \mathrm{W_i} * \mathrm{q_i} \qquad (6)$$

Where SI=sub-index for the various parameters

For computing the WQI, the following equation is used:

$$WQI = \sum \mathrm{SI_i} \qquad (7)$$

Where WQI=Water Quality Index, and SI=sub-index of various parameters

Table 3. The classes proposed for water quality index for drinking (Couillard and Lefebre, 1985).

Class	WQI Range	Type of Water
1	<50	Excellent
2	50-100	Good
3	100-200	Poor
4	200-300	Very poor
5	>300	Unsuitable

Table 4 Parameters used for calculation of water quality index

Parameter	Weight (w_i)	Relative weight (W_i)
pH	4.00	0.11
TH	3.00	0.08
Ca^{2+}	2.00	0.05
Mg^{2+}	2.00	0.05
HCO_3^{-}	3.00	0.08
Cl^{-}	4.00	0.11
TDS	4.00	0.11
F^{-}	4.00	0.11
NO_3^{2-}	5.00	0.13
SO_4^{2-}	4.00	0.11
Fe	3.00	0.08
TOTAL	38.00	1.00

The groundwater quality index shows that all the samples fall within the “excellent category” (Table 5). The low values of WQI in the study area may be attributed to the low concentration of the water quality parameters in the study area. This means the water is not seriously polluted such that it becomes unfit for drinking purpose. However, low pH, is the only health-based concerns observed in groundwater use for drinking and domestic purposes.

The success of irrigation projects depends on both the supply of water and the control of alkali and salt in the soil (Haritash et al., 2008). The use of groundwater for irrigation purpose is dependent on parameters such as Chloride ion, Electrical conductivity, Sodium absorption ratio, Percentage sodium, Permeability index and Residual sodium carbonate (Raju, 2007). The Wilcox diagram (fig. 4) was applied in this study to assess the suitability of the groundwater for irrigation purpose. Based on EC, irrigation water can be classifiedr as low (EC = <250 µS/cm), medium (250–750 µS/cm), high (750–2,250 µS/cm) and very high (2,250– 5,000 µS/cm) salinity classes (Richard, 1955). The use of sodium percentage (%Na) to assess the suitability of groundwater use for irrigation is known globally (Wilcox, 1948). When water contains high %Na, the exchange of Na+ from groundwater and Mg2+ and Ca2+ from the clay particles reduces the soil permeability and eventually results in deterioration of the soil structure and infiltration. According to Ramakrishna (1998), the maximum %Na for irrigation water is 60%. The sodium percentage is calculated by eqn (8).

$$\mathrm{Na\%} = 100 * \frac{\mathrm{Na}^{+}}{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}+\mathrm{Na}^{+}+\mathrm{K}^{+}} \qquad (8)$$

Where, all ionic concentrations are expressed in meq/l (Tank and Chandel, 2010)

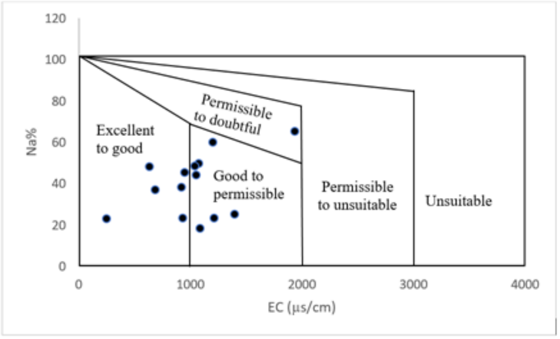


Fig. 4: Rating of groundwater samples of the study area on the basis of EC vs %Na (After Wilcox, 1955)

The excess sum of carbonate and bicarbonate over the sum of calcium and magnesium referred to as residual sodium carbonate (RSC) can also be used to predict the suitability of groundwater for crop irrigation (Raghunath, 1987);

$$\mathrm{RSC} = (\mathrm{CO}_3^{2-} + \mathrm{HCO}_3^{-}) - (\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}) \quad (9)$$

Where, all the ions are expressed in meq/l.

Water with computed RSC values more than 2.5 meq/l is not suitable for irrigation while a value lower than 1.25 meq/l is good. The intermediate concentrations are doubtful. Permeability index formula was proposed by (Doneen, 1964), to measure the soil permeability for assessing the suitability of water for irrigation purpose. PI is calculated using the following equation:

$$\mathrm{PI} = 100 * \frac{\mathrm{Na}^{+} + \sqrt{\mathrm{HCO}_3^{-}}}{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}+\mathrm{Na}^{+}} \qquad (10)$$

where, all ions are expressed in meq/l.

Kelley (1940) and Paliwal (1967) introduced an important parameter to evaluate irrigation water quality based on the level of Na+ measured against Ca2+ and Mg2+. It can be calculated by the equation;

$$\mathrm{KI} = \frac{\mathrm{Na}^{+}}{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}} \qquad (11)$$

where, all the ion concentrations are expressed in meq/L.

A Kelly's ratio (KR) of more than one indicates an excess level of sodium in water. Therefore, water with a KI <1 is suitable for irrigation, while those with KI >1 are unsuitable Narsimha (2013). Generally, calcium and magnesium maintain equilibrium in most waters (Hem, 1985). The measure of the effect of magnesium in irrigated water is expressed as magnesium ratio (MR). MR less than 50% is suitable for irrigation while more than 50% MR is unsuitable for irrigation purpose. Paliwal (1972) proposed a formula for calculating the magnesium hazard (MR) which is;

$$\mathrm{MR} = \frac{\mathrm{Mg}^{2+}}{\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+}} * 100 \qquad (9)$$

where, all ionic concentrations are expressed in meq/l.

Table 5 RSC, PI, MR and KI values of the groundwater samples from Agona East District

No	Community	WQI	Classification	Na%	RSC	PI (%)	MR (%)	KI
1	Pobi	24.79	Excellent	45.52	-1.55	67.68	25.04	0.88
2	Namanwura	22.94	Excellent	23.38	-0.43	58.44	43.53	0.34
3	Kenyakor	29.83	Excellent	38.38	-2.96	55.94	51.60	0.62
4	Amanful	26.25	Excellent	44.17	-1.18	68.76	9.54	0.88
5	Bodjiase	27.77	Excellent	49.95	-1.33	72.41	31.20	1.12
6	Mayenda	35.58	Excellent	25.30	-1.91	49.86	51.40	0.36
7	Kufi Kum	22.04	Excellent	36.99	-0.29	72.22	32.86	0.62
8	Obodakaba	33.29	Excellent	23.40	-1.79	49.47	45.50	0.32
9	Asarkwaa	32.27	Excellent	60.18	-1.72	75.73	49.76	1.56
10	Esusu	29.49	Excellent	18.59	0.13	59.69	30.48	0.31
11	Aboanu	43.34	Excellent	65.37	-2.37	76.81	28.32	1.93
12	Mensakwaa	27.26	Excellent	48.75	-1.61	68.42	45.50	0.96
13	Oboyambo	16.09	Excellent	48.24	-0.12	84.49	70.04	1.02
14	Tawiakwaa	7.82	Excellent	22.96	0.36	124.07	62.56	0.44

The suitability of the groundwater for irrigation purpose is shown by the Wilcox diagram which shows 43% falls within ‘Excellent to good’, 50% falls within ‘Good to permissible’ and 7% ‘permissible to doubtful’ categories (fig. 4). This suggests that the groundwater is generally good for irrigation use. As shown in table 5, all the samples fall within ‘good category’ based on RSC classification. 29% shows ‘unsuitable water’ while 71% shows ‘suitable water’ for irrigation based on KI classification. 21% fall within the ‘I category’ while 79% fall within the ‘II category’. This means all the water samples are suitable for irrigation based on PI classification. 29% shows ‘unsuitable water’ for irrigation based on MR classification while 71% shows ‘suitable water’. The groundwater is generally good for irrigation; however, the high %Na (> 60%), high KI (>1) and High MR (>50%) are the concern observed for the groundwater use for irrigation.

CONCLUSION

The groundwater quality in the Agona East District has been evaluated for drinking and agricultural uses. The study revealed that the major groundwater types in the study area are CaMgCHO3, mixed water and NaCl in decreasing order. The study identified carbonates weathering, silicate weathering, ion exchange together with improper waste disposal as factors influencing the hydrochemistry of the area. Besides the generally low pH of the groundwater, there is no health-based concern observed in groundwater use for drinking and domestic purposes base on the WHO (2012) recommended values and the calculation of WQI which show all the samples taken are excellent water type. The groundwater is also considered suitable for irrigation purposes, however, the high KI values of Bodjiase (KI = 1.12), Asarekwaa (KI = 1.56), Aboanu (1.93), Oboyambo (1.02) greater than KI = 1.00, High MR of Kenyakor (MR = 51.60%), Mayenda (MR = 51.40%), Oboyanbo (MR = 70.04%), Tawiakwaa (MR = 62.56%) and the high %Na value of Abuanu (%Na = 65.366%) are the concerns observed for the groundwater use for irrigation in the study area.

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