UNIVERSITY OF GHANA

ASSESSMENT OF GROUNDWATER QUALITY AND ITS SUITABILITY FOR DOMESTIC AND AGRICULTURAL PURPOSES IN THE NORTH-WESTERN PART OF THE CENTRAL REGION, GHANA.

BY

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MARCH, 2014.

DECLARATION

I hereby declare that this thesis is of my own research work and has not been presented either in part or wholly to any other institution for the award of a degree, or as a research paper. All references cited in this worked have been duly acknowledged.

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ABSTRACT

Groundwater samples collected from 40 institutions and public boreholes within the Twifo Hemang Lower Denkyira (T), Assin North (AN) and Assin South (AS) districts of the Central Region of Ghana were assessed to determine their suitability for domestic and agricultural purposes, based primarily on recommended permissible limits for parameters stated by World Health Organisation. The area covers an area of about 4,199 km^2. The quality assessment was made through the estimation of Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, HCO_3^-, TH, TDS, EC, and pH. Based on these analyses, parameters like SAR, %Na, RSBC, PI, MAR and KR were calculated. The physicochemical parameters analyzed indicate that the order of abundance of the cations concentration is $Ca^{2+}>Na^+>Mg^{2+}>K^+$ while that of the anions is $HCO_3^->Cl^->SO_4^{2-}>NO_3^-$. An appraisal of the Piper diagram reveals that the general groundwater type dominating the study area is Ca-HCO_3. The scatter diagram of $Ca^{2+}+Mg^{2+}$ vs. $HCO_3^-+SO_4^2$ depicts that greater percentage of the samples plot above the equiline illustrating that carbonate weathering is the dominant process producing Ca^{2+} and Mg^{2+} in the groundwater. The relationship, Na+K-Cl vs. Ca+Mg-HCO_3+SO_4 shows that the hydrochemical behavior of the major ions in groundwater is also due to cation exchange processes. The Na+K-Cl ions represent the contribution of sources other than the dissolution of halite to the concentrations of Na^+ and K^+ in water. As per the Gibb's diagram, majority of the samples fall in the rock dominance area indicating that the presence of the major ions is as the result of weathering and dissolution of rocks. The assessment of groundwater in study area reveals that the water is generally suitable for domestic and irrigational purposes.

DEDICATION

This project work is dedicated to the Glory of God, Mrs. Justina Appiah Worwornyo, my children, my siblings, Mr. Reginal Tachie, Lawyer Leonard Sedzro, and to the blessed memory of Madam Vincentia Afua Afetor.

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I cannot lose sight of the contribution of Rev. Mrs. McCauley in granting me the opportunity to pursue this course whilst an employee of her establishment. The same can be said about Mr. Reginald Tackie, a colleague at work, who helped me with tutorial in my taught courses. Madam Comfort Ogbe cannot be left out for her financial assistance throughout the pursuit of the programme.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Groundwater is the most important source of domestic, industrial and agricultural water supply in the world, and assessment of its quality status is important for socio-economic growth and development (Ishaku et al., 2011). Many communities in the developing world depend heavily on groundwater due to increasing pollution with the concomitant rise in the cost of surface water treatment (Kortatsi, 2007). Groundwater quality reflects inputs from the atmosphere, soil and water-rock reactions as well as pollutant sources such as mining, land clearance, agriculture, acid precipitation, and domestic and industrial wastes (Appelo and Postma, 1993; Zhang et al., 2011).

According to WHO (2011a), quality assessment of groundwater is essential to ensure sustainable safe use of the resource for drinking, agricultural, and industrial purposes. In the developing World, 80% of all diseases are directly related to poor drinking water and poor sanitary conditions. Water composition may concentrate salts in soils or water to such an extent that crop yield is affected (Bernstein, 1975). The salt concentration, which may be the result of aquifer properties, determines to a large extent the quality status of groundwater for agricultural purpose, which needs to be assessed with the calculation of environmental factors and indices.

Ackah (2011) states that, rivers, streams and shallow hand-dug wells are traditionally the main sources of water available for use in many rural communities in Ghana, but the question for which limited answer is provided is the unwholesome nature of these water sources. In times when water from these sources is unreliably unavailable, especially during the seasonally dry weather conditions, access to vital water for drinking and other domestic purposes becomes critical. In recent years, the government of Ghana, in collaboration with development partners and Non-Governmental Organisations (NGOs), has provided boreholes to augment and improve the quality of water for some rural communities (Dapaa-Siakwan and Gyau-Boakye, 2000).

The quality of water from boreholes, whether used for drinking, domestic purposes, food production or recreational purposes, has an important impact on health of the population in a country. Water of poor quality can cause disease outbreaks or water-related health problems which can contribute to the rates of disease manifesting themselves on different time scales. Initiatives to manage issues related to safety of water do not only support public health, but often promote socio-economic development and well-being people (WHO, 2011).

Other reasons for the provision of boreholes as an alternative to rivers, hand-dug wells for rural communities lie in the fact that borehole water is presumed to be pathogenically safe, suggesting a zero coliform count per 100 ml of water (Anim et al., 2011). As to whether boreholes are readily available and the water quality is suitable for domestic and irrigation purposes, forms the basis for this study. Water supply especially from the hand-dug wells is polluted due to anthropogenic activities. These activities per WHO (2011b) safe drinking water guidelines include the use of pit latrines by most residents and indiscriminate dumping of household solid wastes which may contribute to the contamination of groundwater in the area.

Therefore, many different water quality parameters are used to determine groundwater suitability for any water usage, since contamination is a possibility. The cost of a monitoring programme and assessing suitability is key and necessary for the local environment or for a specific water use (Babiker et al., 2007). According to Dimitrov et al. (2008), a system for assessing the suitability of available water for irrigation is also related to the requirements of the different crops under cultivation. It is also imperative to consider the result of the chemical laboratory analysis to avoid emerging problems at using inappropriate quality water.

1.2 PROBLEM STATEMENT

Groundwater remains one of the purest forms of water available in nature for domestic purposes and meets the overall demand of rural and semi-urban communities. However, the development of human societies and technological advancement result in bio-environmental problems (Dimitrov et al., 2008). Thus, the use of farm implements and agro-chemicals (e.g. NO_3^-) render the soil an impure medium that releases and allows contaminants into groundwater systems during recharge or discharge (Dimitrov et al., 2008).

Generally, characteristics of irrigation water vary with the source of the water (Ayers and Westcott, 1985). Regional differences in groundwater characteristics will result from variation of geology and climatic parameters. Moreover, there may also be great differences in the quality of water available on a local level depending on whether the source is from surface water bodies (rivers and ponds) or from aquifers with varying geology, and whether the water has been chemically treated. According to Rowe et al. (1995), the chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering plant availability of nutrients.

Usually, possible sources of contamination are anthropogenic and natural, that occur in the proximity of water bodies and are likely to influence water quality from the ground (Anim et al., 2010). For example, in some places, refuse dumps and places of convenience (toilets) are sited close to well locations. In other cases, organic and inorganic wastes as well as wastewater from various human activities have been disposed of near or into water bodies, which also served as sources of water for some the communities. WHO (2008) states that there is therefore a high level of probability that these substances, both organic and inorganic, contaminate the water in aquifers that are shallow, which are below or adjacent to these sources of contamination.

Rural areas in Ghana, and recently several urban communities, depend greatly on groundwater resources for domestic and agricultural purposes. This requires that the water meets certain minimum standards with respect to its quality. However, geogenic and anthropogenic processes and activities respectively negatively affect groundwater resources and therefore render it unsuitable for the purposes stated. Therefore, most of the groundwater resources tapped through boreholes, hand-dug wells are not without quality problems, notably high concentrations of fluoride, iron, manganese, nitrate, among others, and sometimes coliform bacteria. As a result, the study seeks to assess and evaluate groundwater resources in the study area for its suitability for domestic and agricultural purposes.

1.3 OBJECTIVES OF THE STUDY

The objectives of the study are to;

(a) determine of the major water types and the mechanisms responsible for groundwater hydrochemistry in the area;

(b) evaluate the quality of groundwater and its suitability for domestic and irrigation purposes.

1.4 JUSTIFICATION FOR THE STUDY

Several studies in groundwater quality and its suitability for domestic and irrigational purposes have been carried out both in Ghana and elsewhere (e.g., Abdul-Razak et al., 2009; Bauder et al., 2010; Obiefuna and Sheriff, 2010; Yidana et al., 2010; Ackah et al., 2011; Sarukkalige, 2011). However, all these studies were conducted in areas outside the current study area.

This study when completed, would give a scientific base for a policy formulation, a programme or a practical contribution to solving problem related to domestic and irrigation uses of groundwater in the said area. Again, the research would provide information and knowledge as to which water type is suitable for domestic or irrigation purposes for the rapidly developing area.

1.5 THE STUDY AREA

1.5.1 Geographical Location and Accessibility

The study area consists of three administrative assemblies namely Assin North Municipal (AN), Assin South Municipal (AS) and Twifo Hemang Lower Denkyira District (T) of the Central Region of Ghana. It lies within longitudes 1°50’ and 1°05’ West and latitudes 5° 15’ and 5° 55’

North (Fig 1.1). It is bounded on the north by Ashanti Region, on the south by Abura Asebu Kwamankese, Cape Coast and Komenda-Edina-Eguafo-Abirem districts, on the east by Asikuma Odoben-Brakwa and Ajumako Enyan-Esiam districts, and on the west by Upper Denkyira East and Mpohor Wassa East districts. It covers an area of about 4,199 km^2 (Population and Housing Census, 2010). Aside Assin Fosu, Nsuaem-Kyekyewere and **Twifo Praso** as the administrative capitals respectively, other towns include Assin Nyankumasi, Assin Akonfudi, Assin Bereku, Assin Praso, Assin Kushea, Nsuta, Ongua, Assin Akyiase, Assin Ngresi, Gyaka, among others.

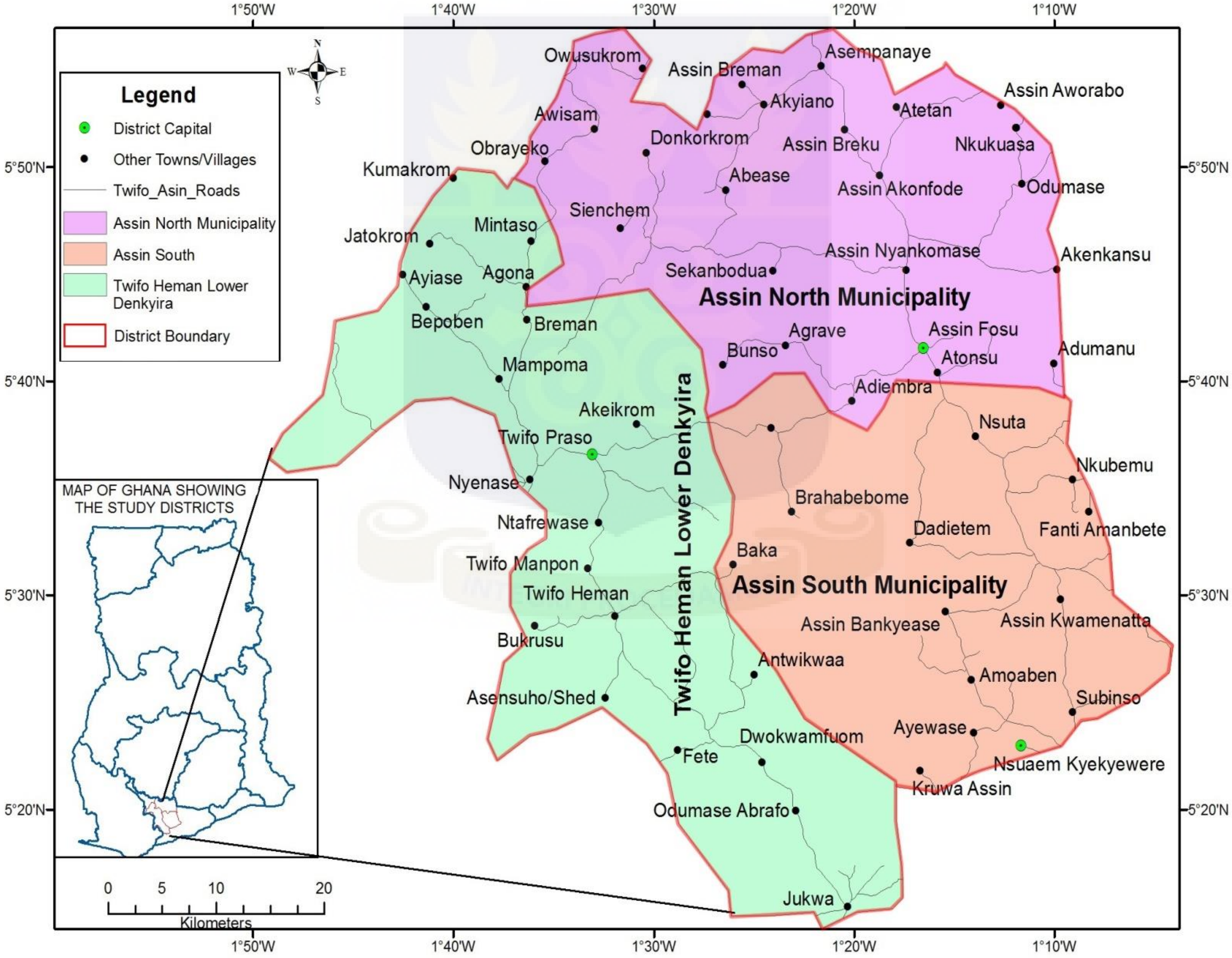

Fig 1.1: Geographical Location and Size of the Study Area

1.5.2 Topography and Drainage

In terms of topography and drainage, the study area is characterized by undulating topography and dissected peneplain, and has an average elevation between 70 and 200 m above sea level. Flood-prone plains of rivers and streams lay low below sea level. The study area has numerous small rivers and streams with the main ones being the Pra, Offin, Betinsin Obuo, Bimpong, Fum and Ongua draining the area. Swamps are also abound in the study area which serve as potentials for fish farming and dry season vegetable and rice farming.

1.5.3 Climate and Vegetation

The area falls within the moist tropical forest, mainly deciduous, and has an annual rainfall between 1500 and 2000 mm. Annual temperatures are high and range between 30°C from March to April and about 26°C in August (www.ghanadistricts.com). Average relative humidity is high ranging from 60% to 70%. There are forest reserves like Bimpong, Assin, Minta, Bunsaben, Baku Forest Reserves, and Kakum National Park. These reserves serve as protective cover to some of the major rivers that drain the area (www.ghanadistricts.com). The Kakum Forest Reserve has been developed into a tourist site which generates foreign exchange and income for the local economy and the nation as a whole. However, the area's vegetation has been largely disturbed by the activities of man through farming, logging and mining among others.

1.5.4 Geology and Soil

The regional geology of southern Ghana generally and largely comprised of thick sequences of steeply dipping metasedimentary rocks, alternating with metavolcanic units of Proterozoic age rocks. Rocks of the Birimian system underlie most of southern, western, and northern Ghana, and host most of the gold and diamond deposits in the country. The Birimian consists of metamorphosed volcanic and sedimentary rocks that form five sub-parallel belts of volcanic rock separated by broad basins of sedimentary rocks (Yidana, 2011). These include metamorphosed lava, pyroclastic rock, hypabyssal basic intrusive, phyllites and greywacke. From the geological map (Fig 1.2) of the study area, almost the entire study area is underlain by the Bain-type Granitoids complex (consisting of biotite, hornblende, muscovite, biotite gneiss) belonging to the Precambrian formation.

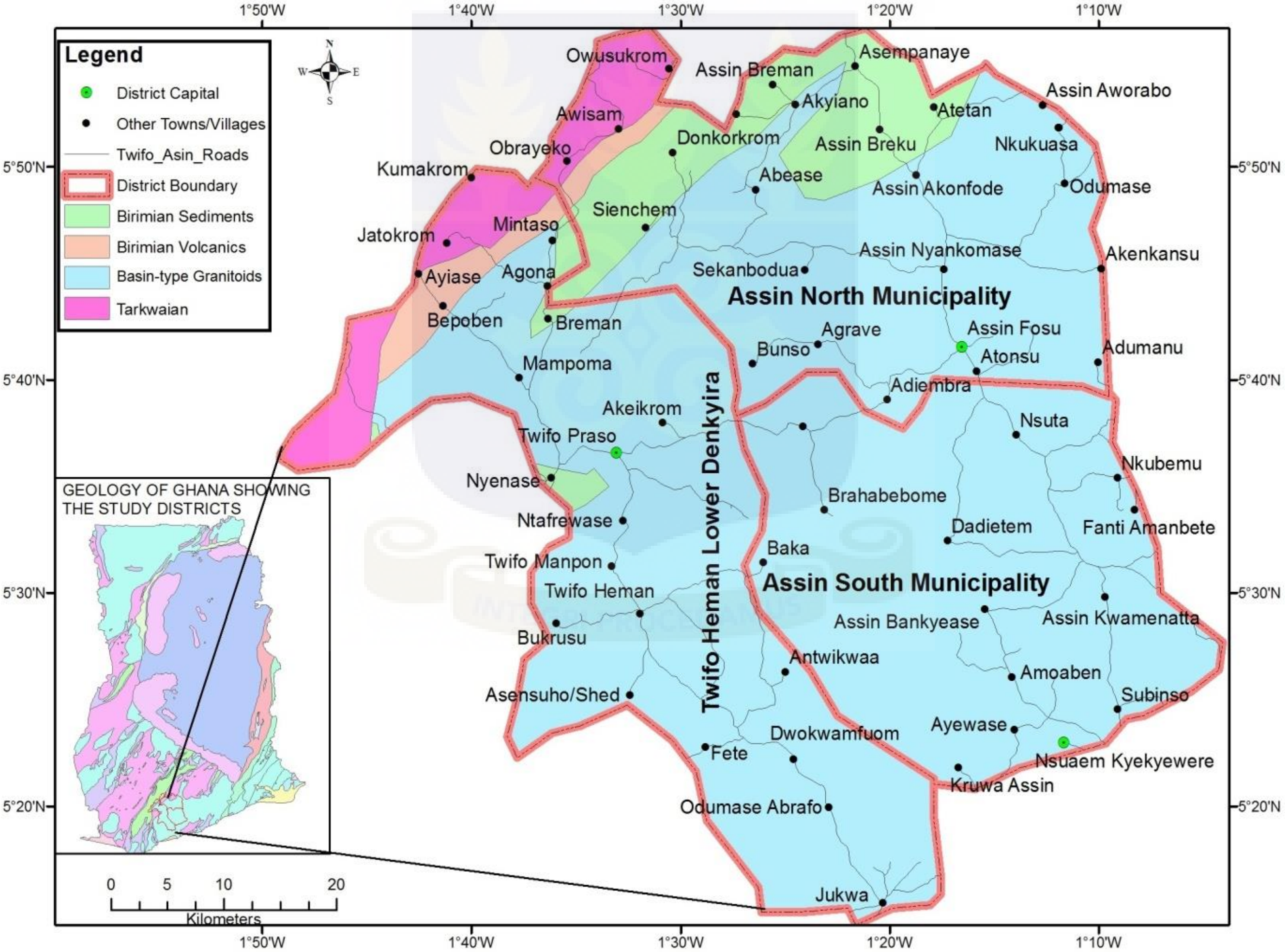

Fig 1.2: The Geology of the Study Area

Rocks of the Birimian system consist of predominantly metasedimentary and metavolcanic rocks such as phyllites, schist, tuff and greywacke (Junner 1935, 1940; Bates 1955). It comprises basically of granites and adamellites, schistose in some communities and very massive in others. It also includes several components ranging in composition from grandiorites to granites and their migmatitic varieties. The predominant fluoromica minerals are muscovite and biotite in the communities, which are however, underlain by the lower Birimian phyllites.

The soils associated with the Precambrian and Birimian geological formations found in the southern section of the area under study are Bekwai-Nsiama-Oda compound suitable for the cultivation of perennial tree crops such as coconut, cocoa, coffee, oil palm and citrus, and food crops such as maize, plantain, cassava and cocoyam. They are found around Bepobeng, Mosease, Nyenase, Tweapease, Juaso-Manso, Kyekyewere-Kakum, Jukwa, Mampong, Ntafrewaso, Watreso and Krobo.

1.5.5 Demographic and Economic Characteristics

The total population of the study area released by Population and Housing Census (PHC) is 382,459 with population density of 91 persons per sq.km (PHC, 2010). The population distribution in the district shows that 49.37% (188,814) are males while 50.63% (193,645) are females, which agrees with the national distribution where there are more females (51.2%) than males (48.8%) (PHC, 2010). One of the major economic activities of the people is agriculture. Arable farming is the major agricultural occupation with farmers producing mainly food crops (cassava, maize, plantain, cocoyam, rice, beans and groundnuts). Others deal with livestock like cattle, sheep, goats and pigs in abundance (www.ghanadistricts.com).

CHAPTER TWO

LITERATURE REVIEW

Africa has the lowest total potable water supply coverage in the world, with only 62% of the population having access to improved water supply (Global Water Supply and Sanitation Assessment, 2000). This figure is based on estimates from countries that represent approximately 96% of Africa's total population. In global terms, the continent contains 28% of the world's population without access to improved water supply (Global Water Supply and Sanitation Assessment, 2000). In the report, it is predicted that Africa will face increased population growth over the coming decades, with the greatest increase coming in urban areas.

As a result, approximately 210 million people in urban areas will need to be provided with access to water supply services, if the international coverage targets for 2015 are to be met. According to the Global Water Supply and Sanitation Assessment (2000), a similar number of people in rural areas will also need to gain access to water supply services. Given the findings concerning change in coverage over the 1990s, it appears that future needs for rural services may continue to be the most difficult to meet (Global Water Supply and Sanitation Assessment, 2000).

For monitoring purposes, the use of improved drinking water sources has been equated to access to safe drinking water, but not all improved sources provide drinking water that is safe (WHO, 2011a). China and India are home to more than a third of the world population and both countries have made considerable progress in the supply of safe drinking water. For example, in China, 89% of the population of 1.3 billion uses drinking water from improved sources, up from

67% in 1990. In India, 88% of the population of 1.2 billion uses drinking-water from such sources, as compared to 72% in 1990 (WHO, 2011a).

To achieve the Millennium Development Goal (MDGs), quality of groundwater and its suitability for domestic and irrigation purposes should be of great concern to all stakeholders in the water sector (WHO, 2011a). According to Gibbs (1970), a number of factors such as rock weathering, atmospheric precipitation, evaporation and crystallization control the chemistry and quality of groundwater.

WHO (2008; 2011b) identify that contaminated water serves as a mechanism through which communicable diseases such as diarrhoea, cholera, dysentery, typhoid and guinea worm infection are transmitted. WHO (2011b) estimates that diarrhoea alone claimed the lives of 2.5 million people. For children under five, this situation is worse than the combined burden of HIV/AIDS and malaria the same year.

The challenges being faced by underdeveloped and developing countries with regard to the recent trends, growth and development of their economies are their inability to study movement of water contaminants in the subsurface, components and quality of groundwater, their suitability for drinking and irrigation, interpretation of hydraulic and hydrological data, development and prudent management of water resources (Rassam and Werner, 2008).

The study area is predominantly agrarian, with about 60% of the people engaged in rain-fed agriculture (Ghana Strategy Support Program, 2012). As a result of climate change, the area in recent times is experiencing erratic rainfall regime which poses a lot of problems to the inhabitants especially those into vegetables cultivation. Monthly total and mean rainfall decreased about 2.4% per decade over the 50 years, though in the 1960s, the rainfall over Ghana was particularly high (Ghana Strategy Support Program, 2012).

The quality of groundwater is constantly changing in response to daily, seasonal and climatic factors. Continuous monitoring of water quality parameters is highly crucial because changes in the quality of water have far reaching consequences in terms of its effects on man, plants and animals. According to Water Resource Commission (2003), Ghana, groundwater resources are under increasing pressure in response to threats of rapid population growth, coupled with the establishment of human settlements, and increasing industrial development. In several developing countries, irrigation represents up to 95% of water groundwater uses, and plays a major role in food production and food security (UNESCO, 2007). Future agricultural development strategies of most of these countries depend on the possibility to maintain, improve and expand irrigated agriculture.

The importance of groundwater quality in human health has recently attracted a great deal of interest (Vasanthavisar et al., 2010). In the developing World, 80% of all diseases are directly related to poor drinking water and unsanitary conditions (UNESCO, 2007). On the other hand, water composition may concentrate salts in soils or water to such an extent that crop yield is affected (Bernstein, 1975). The quality status of an aquifer can be assessed with the use/calculation of environmental factors and indices, which include a wide spectrum of parameters. The authors further stressed that such factors may become a valuable tool for the assessment of environmental conditions of an area.

The toxicity of trace metals in groundwater depends on the concentration of the metals above a certain level, which could be considered as essential for health issues (WHO, 2011b). This means that water quality data is essential for the monitoring and implementing of programmes responsible for water quality regulations, characterizing and remediating contamination and for the protection of the health of humans (as in drinking) and the ecosystem (as in irrigation) (WHO, 2011). Regular monitoring of groundwater resources thus plays a key role in sustainable management of water resources.

Rahman et al. (2012) indicated that high salinity and other chemical concentrations in groundwater directly affected soils and crops, and their management. They concluded that it is possible to produce high quality crops only by using high-quality irrigation water when other inputs are kept optimal. The regional differences in water characteristics result from variation of geology and climatic parameters (Shirazi et al., 2011).

In assessing the suitability of groundwater for irrigation, one of the parameters that comes to mind is salinity, which is the amount of dissolved salt in water (Ishaku et al., 2012). Salinity directly affects soil properties through an increase in soil solution osmotic pressure and soil structure, permeability and aeration, which can have adverse effects on plant growth and crop performance in general (Thorne and Peterson, 1954). The cations and anions most frequently found in irrigation water whose combination has consequences for soil properties are: sodium, calcium, magnesium, chloride, sulphate, and bicarbonate (Ackah et al., 2012).

European Union Water Framework Directive in the field of agricultural water management is one of the systems based mainly on Food and Agricultural Organisation (FAO) methodology on water quality for agriculture (Ayers and Westcot, 1985). It contains recommendations as to how to use water for irrigation on the basis of laboratory analysis and on the information of cultivated crops, soil and agro-climatic characteristics of the region. The dependence on groundwater is increasing in many regions because of limited surface water as perennial rivers get dried frequent during dry spells. This leads to abstraction of the groundwater resource resulting heavily stressed aquifers and low yield (Elampooranan et al., 1999).

According to Bhat et al. (2013), the major cations (calcium and magnesium) present in groundwater are particularly derived from leaching of limestone, dolomites, gypsum and anhydrites. The calcium ions can also be derived from cation exchange process (Garrels, 1976). Their study showed that carbonate weathering is the dominant process for supply of the calcium and magnesium ions to the groundwater.

The possible source of sodium concentration in groundwater is due to dissolution and weathering of sodium bearing minerals (Bhat et al., 2013). If the halite dissolution process is responsible for the sodium concentration in groundwater, Na/Cl ratio should be approximately 1, whereas the Na/Cl ratio greater than 1 typically indicates that the sodium was released from silicate weathering (Meyback, 1987). Bhat et al. (2013) observed that majority of the samples in their study show Na/Cl ratio greater than 1 indicating that the silicate weathering is the dominant process for the release of sodium in the groundwater.

One of the sources of carbonate and bicarbonate concentration in groundwater is carbonate weathering as well as dissolution of carbonic acid in the aquifers (Jeevanandam et al. 2006; Kumar et al. 2009). Bhat et al. (2013) found out in their study that, bicarbonate is the dominant anion and its increased level may be attributed to availability of the carbonate minerals in the recharge area. The chloride ions in the same study from natural process such as weathering, dissolution of salt deposits, and irrigation drainage return flow are responsible for chloride content in the groundwater (Lusczynski and Swarzenski 1996). The sulphate ions are derived from weathering of sulfate and gypsum-bearing sedimentary rocks (Elango et al. 2003; Jeevanandam et al. 2006), and sources of nitrate content in the groundwater of the may be credited to the irrigation return flow as lot of fertilizers are used in the agricultural fields in and around the study area.

The influence of geology on water quality is very complex and can be ascribed to the processes controlling the exchange of chemicals between the geology (aquifer) and water (Hesterberg, 1998). Apart from natural factors (e.g. geology) influencing water quality, human activities such as domestic and agricultural practices impact negatively on groundwater quality (Ackah et al., 2011). Pollution of water bodies as a result of metal toxicity has also become a source of concern among water providers and consumers (Ackah et al., 2011). This concern has become alarming in response to increasing knowledge on their toxicity to human health and biological systems (Anazawa et al., 2004).

Van-Sambeek et al. (2000) assessed the chemical composition of groundwater resources and the groundwater from the various locations of study area limited and of poor quality for irrigation purposes. The groundwater of the area is brackish, due to both seawater mixing and the semi-arid climatic conditions. They observed that in suburban areas, anthropogenic factors (use of agro-chemicals, waste disposal) affected the groundwater quality in terms of high nitrate concentrations, and agricultural (waste) water infiltrated which replenished the aquifer, and has a desalinization effect on the groundwater quality.

Subramanian and Saxena (1983) are of the view that a conductivity value of groundwater commonly used in determining the suitability of water for, say, irrigation is problematic. Cox et al. (1966) also suggested that such an approach is questionable particularly for waters containing significant amounts of ions such as bicarbonate and sulphate and also of natural species such as dissolved silica. Subramanian and Saxena (1983) concluded that the chemical composition of groundwater in Delhi is controlled by geology and rainwater. They indicated that carbonate and silicate systems together control the alkaline pH of groundwater. They are of the view that ions such as Cl^- and SO_4^{2-}, from secondary sources such as drain and waste water, could be responsible for groundwater contamination.

A study of groundwater quality and its related effects on domestic and irrigation purposes by Rao et al. (2005), showed that over-exploitation of groundwater results in decline of water levels, leading to intrusion of salt water along coastal regions, which is a natural phenomenon. The study showed that most of the wells observed contained brackish groundwater. The rest of the wells according to them showed a fresh water environment. Their results suggested that the brackish nature in most of the groundwaters is not due to the seawater influence, but is caused by the hydrogeochemical process. However some influence of seawater on the groundwater quality was observed along the rock fractures, and the combined effect of seawater and urban wastewaters results in the inferior quality of groundwater in a few wells, especially in terms of its suitability for domestic purposes (Rao et al., 2005).

Analytical results of groundwater quality in Jada and its environs in Nigerian indicated that the groundwater quality is good for human consumption based on Revelle and Contamination indices but poses health risk due to bacteriological contamination (Ishaku et al., 2012). This contamination sources could be the presence of landfills, latrines and wastewater discharge from homes. EC, TDS and TH values indicate good quality water for irrigation practice. The values of permeability index (PI) and magnesium adsorption ratio (MR) showed that groundwater quality is unsuitable for irrigation practice. Chloro-Alkaline Indices show positive values which indicate exchange of Na and K from water with Mg and Ca of the rocks.

The most damaging effects of poor-quality irrigation water are excessive accumulation of soluble salts and/or sodium in soil which makes the soil moisture more difficult for plants to extract, and crops become water stressed even when the soil is moist (Alsobrook, 1994). When excessive sodium accumulates in the soil, it causes clay and humus particles to float into and plug up large soil pores. This plugging action reduces water movement into and through the soil, thus crop roots do not get enough water even though water may be standing on the soil surface (Alsobrook, 1994).

According to Ebrahimi et al. (2011), groundwater quality during dry years is downgraded after initial wet year period of good water quality. The results also showed that water quality variation could be attributed to the presence of calcium, magnesium and sodium sulphate concentrations in alluvial materials, which are the main groundwater contaminants (Ghayomian et al., 2005).

Groundwater quality assessment study done by Sarukkalige (2011) indicated that groundwater beneath agricultural land is particularly susceptible to nutrient loading due to the application of fertilizers. It is also observed that numerous contamination plumes from industrial areas continue to migrate with the groundwater flow. Several areas including rural areas, high density urban areas and industrial areas are therefore identified as the vulnerable areas for groundwater contamination (Sarukkalige, 2011).

Assessment of the quality of groundwater has been carried out by Tikle et al. (2012) where it was observed that the quality of water in study area varies in relation to their suitability domestic purposes. The pollution and contamination levels in the water is as the result of anthropogenic activities, and the concentration of fluoride may have an increasing trend, as Bhosle et al. (2001) note that the discharge of domestic wastes from the surrounding industries increases fluoride values.

Viero et al. (2008) also observed that the dissolution of fluorite occurs at the same time as calcite and dolomite solubilization. The concentration of fluoride in the groundwater is found to exceed the maximum limit for drinking waters (1.5 mg/L), in this case, the fluoride arises through the solubilization of fluorite veins in granitic and gneissic aquifers (Roisenberg et al., 2003).

Calcium also combines with fluoride, resulting in the ionic species calcium fluoride, which is unstable in groundwater (Gaciri and Davies, 1992).

The results from hydrochemical analysis of groundwater by Bhardwaj et al. (2009) show that the water samples have EC, TDS, Na^+, Mg^{2+}, HCO_3^- and TH higher than the WHO (1997) maximum desirable limits. The main hydrochemical facies of the aquifer (Ca-Mg–HCO_3) represents 33.33% of the total wells. They indicated that the high values of hydrochemical parameters are as the result of dissolution of salts, precipitation of dolomite, and ion exchange.

Results from a study by Suh (2004) revealed that major ion compositions of groundwater are predominantly Na>Mg>Ca>K:Cl>SO4>HCO_3 which is influenced by different types of waste materials (construction materials or dredged marine sediments) deposited in the study area. They also find out that major ions concentration order come from areas of dredged marine infill sediments are responsible for Na>Ca>Mg>K:HCO_3>Cl>SO_4.

Kusimi (2007) investigated the levels of pollution of groundwater resources by heavy metals released into the environment from mining activities. Concentration levels of iron and zinc have exceeded WHO permissible limits. He discovered that iron is strongly influenced by the oxidation of pyrite and arsenopyrite (iron-bearing rocks) in the underlying geological formations while the zinc occurrence is also associated with sulphide ore in the Prestea mine.

Groundwater quality and its suitability for drinking purposes were studied by Deshmukh (2011). It was found out that the parameters like TDS, Na, Ca, Mg, total hardness and nitrate values exceeded the WHO (1991) permissible limit in the majority of the samples particularly from irrigated area, which proves that water quality in most of the villages in the irrigated area is unsuitable for domestic purposes and proper treatment is needed before using it for drinking purpose.

The results of a study in the Keta Basin in the Volta Region of Ghana indicated that anthropogenic factors are the second-most influential on groundwater hydrochemistry in Ghana besides mineral weathering and saline water intrusion (Yidana, 2010). It was found out that Keta Basin is highly affected since its aquifers are relatively shallow and chemicals are heavily used. The third-most important contributor is the oxidation of organic carbon by nitrate (Yidana, 2010).

Yidana (2011) observes that two major groundwater types exist in Ghana, namely: the Na-Cl groundwater types which are associated with the coastal aquifers where groundwater salinity is high and Na-K-HCO_3 groundwater types, which dominate aquifers farther away from the coast. Yidana (2011) indicates that mineral weathering and saline water intrusion are the major source of variation in the hydrochemistry of groundwater in Ghana, resulting in Na-K-HCO_3 and Na-Cl groundwater types respectively.

The groundwater in the Thiruvananthapuram District, Kerala-India generally showed an acidic trend as evidenced by the low pH values, particularly in lateritic aquifers (Kumar and Divya, 2012). The groundwater associated with the post-monsoon season is of Na-Cl facies which slightly changes to Na-Mg-Cl facies during pre-monsoon. The study showed that the concentration of EC and TDS exceed the recommended limits and hence mitigation measures are needed to be adopted to ensure safe drinking water. Probable reason for this phenomenon could be the mixture of leachate from the municipal waste especially in urban centers, and fertilizers from rubber plantation in certain other places in the midland.

Ananthakrishnan et al. (2012) observed that most of the parameters (calcium, magnesium, sulphate) of the samples registered higher values beyond the WHO maximum recommended limits, which minimizes the suitability of the samples for drinking purpose without treatment. In most of the samples Mg^{2+} falls above the standard desirable limit is mainly attributed to the abundant availability of limestone in the area (Lakshmanan et al., 2003), and also may be due the dissolution of magnesium calcite, gypsum and dolomite (Garrels and Christ, 1965; Rao, 1997).

The results from a study by Ahamed et al. (2013) indicated that Cl^-, alkalinity, TH, EC, TDS, Na^+ and K^+ were found in excess in most of the samples. The hydro geochemical analysis revealed that the groundwater in the study area is better for irrigation and unfit for drinking purposes. The alkaline earths (Ca^{2+} and Mg^{2+}) exceed the alkalis (Na^+ and K^+) and Cl^- exceeds other anions. The water quality based on WQI reveals that samples falls in poor, very poor and unfit for drinking purposes respectively. The occurrence of high EC values in the study area reflects the addition of some salts through the prevailing agricultural activities (Milovanovic, 2007). Some of the samples are doubtful for irrigation purposes based on Na% values.

Deshmukh (2011) indicated that parameters like TDS, Na, Ca, Mg, TH and NO_3^- have exceeded the prescribed limits in the majority of the samples particularly from the irrigated area. TDS of groundwater indicated slightly saline to moderately saline to very saline groundwater properties which suggests that the quality of groundwater from irrigated land use is almost unsatisfactory for drinking purpose. Intensive irrigation along with monoculture type of cropping pattern besides excess use of nitrogenous fertilizers are possible causes of high concentration of nitrate in the groundwater (Shrivastava, 1995; Berg et al., 2001). The groundwater can be categorized as very hard to extremely hard category (Deshmukh, 2011).

According to Deshpande and Aher (2011), higher concentration of total dissolved solids, electrical conductivity, chloride, total hardness and magnesium in groundwater samples of parts of Vaijapur (India) indicated signs of deterioration as per WHO and Bureau of India Standards. These analytical results showed 40% groundwater sample is unsuitable for irrigation purposes based on irrigation quality parameters. The study also revealed that application of fertilizer for agricultural purposes contributed to the higher concentration of ions which can degrade in varying degrees the aquifer of Vaijapur.

Tank and Singh (2010) did a comparison of the concentration of the chemical constituents of groundwater samples with WHO (1983) standards for drinking water and realized that NO_3^- concentrations were in an alarming state with respect to the use of groundwater for domestic purposes. NO_3^- concentration in groundwater samples range from 11 to 228 with an average value of 126.27 mg/L. Nearly 81% samples exceed the desirable limit of 45 mg/L as per WHO norms. The high concentration of nitrate in drinking water is toxic and causes methemoglobinemia (blue baby disease) in children and gastric carcinomas (Comly, 1945).

Wang (2013) discovered that the main hydrochemical processes that affect the water quality of the groundwater system include silicate mineral weathering, dissolution, ion exchange, and, to a lesser extent, evaporation, which seem to be more pronounced down-gradient of the flow system. The results of Wang (2013) assessment of groundwater samples indicated that the groundwater in the study area is generally hard, fresh to brackish, high to very high saline, and low alkaline in nature. The high total hardness and TDS of the groundwater in several places indicate the unsuitability of the groundwater for drinking and irrigation.

Traditionally, the main reason for the assessment of the quality of groundwater has been, to verify whether the observed water quality is suitable for intended uses. The use of monitoring has also evolved to help determine trends in the quality of the aquatic environment and how that quality is affected by the release of contaminants, other anthropogenic activities, and/or by waste treatment operations (Meybeck et al., 1996). More recently, monitoring has been carried out to estimate nutrient or pollutant fluxes discharged by rivers or groundwaters to lakes and oceans, or across international boundaries. Monitoring to determine the background quality of the aquatic environment is also now widely carried out, as it provides a means of comparison with impact monitoring. It is also used simply to check whether any unexpected change is occurring in otherwise pristine conditions, for example, through the long range transport of atmospheric pollutants (Meybeck et al., 1996).

According to Sarkar and Hassan (2006), quality of water is “a pre-requisite for the success of an irrigation project”. They observed in their study that the compositions of the groundwater samples were within the permissible range of irrigation use, except an increased Cl^- value, responsible for toxicity problem. It was also found that standard water quality parameter indices for irrigation were also found within acceptable range. High RSC values beyond the permissible limit (2.5 meq/L) can be attributed to higher HCO_3^- content in the irrigation water, and this may induce some permeability problems.

Considering the continued development and increasing use of groundwater combined with its reuse, the quality of groundwater suffers unless consideration is given to protecting it (WHO, 2011). Water is practically a universal solvent and dissolves some of everything it comes in contact with. The chemical quality of the groundwater is a factor which is of paramount importance in its utilization for municipal and irrigational uses. To establish the criteria for measuring quality of groundwater, chemical, physical and bacteriological constituents must be specified. In this work, an attempt is being made to study the chemical and physical parameters as constituents of groundwater in parts of the Central Region of Ghana and its suitability for domestic and irrigation purposes.

Hydrochemical evaluation of groundwater systems is usually based on the availability of a large amount of information concerning groundwater chemistry (Aghazadeh and Mogaddam, 2004; Hossien, 2004). Quality of groundwater is equally important as its quantity in determining suitability for various purposes (Subramani et al., 2005). Groundwater chemistry, in turn, depends on a number of factors, such as general geology, degree of chemical weathering of the various rock types, quality of recharge water and inputs from sources other than water rock interaction. Such factors and their interactions result in a complex groundwater quality (Sunne et al., 2005). The rapid increase in the population (Population and Housing Census, 2010;

www.ghanadistricts.com) has led to large scale groundwater developments in the study area. Intense agricultural and urban development has caused a high demand on groundwater resources in dry spells of the study area while putting these resources at greater risk to contamination.

Understanding the aquifer hydraulic properties and hydrochemical characteristics of water is crucial for groundwater planning and management. Generally, the motion of groundwater along its flow paths below the ground surface increases the concentration of the chemical species (Domenico and Schwartz, 1990; Freeze and Cherry, 1979; Kortatsi, 2007). Hence, the chemistry could reveal important information on the geological history of the aquifers and the suitability of groundwater for domestic, industrial and agricultural purposes. Moreover, pumping tests with the drilling results are the most important information available for the groundwater investigations, as they are the only methods that provide information on the hydraulic behaviour of wells and reservoir boundaries (Barkic, 2003; Elkrai1et al., 2004).

pH measurements are given on a scale of 0.0 to 14.0. Pure water has a pH of 7.0 and is neutral; water measuring fewer than 7.0 is acidic; and that above 7.0 is alkaline or basic (Environmental Protection Agency, 2006). Low pH is usually caused by high levels of hydrogen ions through excessive use of acidic fertilizers close to water bodies recharging aquifers, as well as rocks containing gypsum and calcium carbonate. Most estuarine organisms prefer conditions with pH values ranging from about 6.5 to 8.5. Values of pH are based on the logarithmic scale, meaning that for each 1.0 change of pH, acidity or alkalinity changes by a factor of ten; that is, a pH of 5.0 is ten times more acidic than 6.0 and 100 times more acidic than 7.0. When the hydrogen and hydroxyl ions are present in equal number (the neutral point), the pH of the solution is 7.

Alkalinity is influenced by rocks and soils, salts, certain plant activities, and certain industrial wastewater discharges. Some water can test on the acid side of the pH scale and still rank high in alkalinity! This means that, while the water might be acidic, it still has a capacity to buffer, or neutralizes acids. Total alkalinity is measured by measuring the amount of acid (e.g., sulfuric acid) needed to bring the sample to a pH of 4.2 (Environmental Protection Agency, 2006). According to Ramesh and Bhuvana (2012), total hardness can result from the dissolution of limestone deposits ($CaCO_3$), and the excess concentration of calcium makes water hard. Normally, the distance at which limestone beds are found from the surface with intercalated shale and gypsum corresponds to the depth range of the sampled wells. Therefore, one may probably conclude that this limestone deposits is considered responsible for hardness in that area.

Excess sodium in irrigation water produces undesirable effects of changing soil properties and reducing soil permeability (Kelly, 1951). High sodium depositing waters are generally not suitable for irrigating crops, as higher deposition of sodium may deteriorate the soil characteristics. SAR of water is directly related to the adsorption of sodium by soil and is a valuable criterion for determining the suitability of the water for irrigation. Excessive sodium content relative to calcium and magnesium reduces soil permeability (Kelly, 1951), and thus inhibits the supply of water needed for the crops. The SAR measures the relative proportion of sodium ions to those of calcium and magnesium in water. SAR is used to predict the sodium hazard of high carbonate waters especially if they contain no residual alkali (Bhat et al., 2013).

Magnesium Adsorption Ratio (MAR) deals with magnesium content of water which is considered one of the most important qualitative criteria in determining the quality of water for irrigation. Generally, calcium and magnesium maintain a state of equilibrium in most waters.

More magnesium in water will adversely affect crop yields as the soils become more saline (Joshi et al., 2009). Permeability Index (PI) on the other hand determines how soil permeability is affected by the long-term use of irrigated water and the influencing constituents are the total dissolved solids, sodium bicarbonate and the soil type (Doneen, 1964).

If the concentration of Na^+ is high in irrigation water, Na^+ gets absorbed by clay particles, displacing Mg^{2+} and Ca^{2+} ions. This exchange process in soil reduces the permeability of the soil and eventually results in poor internal drainage of the soil (Collins and Jenkins, 1996). Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry (Saleh et al., 1999). Methods of Wilcox (1955) and Richards (1954) have been used to classify and understand the basic character of the chemical composition of groundwater, since the suitability of the groundwater for irrigation depends on the mineralization of water and its effect on plants and soil. According to Yidana et al. (2010), percentage sodium (%Na) is an assessment of the suitability of groundwater for irrigation, based on the content of sodium compared to the total cations in the system. High sodium waters are not suited for irrigation activities because the sodium ion engages in cation exchange processes which tend to affect the ability of soils to sustain crop productivity.

When concentrations of carbonates and bicarbonates exceed that of calcium and magnesium, there may be possibility of complete precipitation of calcium and magnesium (Bhat et al., 2013). Bicarbonate and carbonate are considered to be detrimental to the physical properties of soils, as it causes dissolution of organic matter in the soil, which in turn leaves a black stain on the soil surface on drying. Residual Sodium Bicarbonate (RSBC) is employed in determining the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose (Aghazadeh and Mogaddam, 2010). Classification of irrigation water containing more than 2.5 meq/l of RSBC is not suitable for irrigation.

There are several methods by which hydrogeochemical data of a study area can be easily displayed. One of such methods is Piper Trilinear diagram (Piper, 1944). This plot includes two triangles, one on left hand side for plotting cations and the other on right hand side for plotting anions. The cation and anion fields are then combined to show a single point in a central diamond shaped field from which inference is drawn on the basis of the hydrogeochemical facies concept. This diagram reveals similarities and differences among groundwater samples because those with similar qualities will tend to plot together as groups (Todd, 2001).

The Piper diagram is very useful in bringing out chemical relationships among groundwater in more definite terms (Todd, 2001). In the diagrams, the concentrations are expressed as %meq/L. Many water analyses can be plotted on the same diagram and it is used to classify waters by hydrochemical facies. It is also used to identify mixing of waters, and track changes through space and temporal relationships. However, concentrations of ions are renormalized, and cannot easily accommodate waters where other cations or anions may be significant.

Another technique used in displaying hydrogeochemical data is the Gibbs diagrams. It illustrates the groundwater chemistry and the relationship of the chemical components of water to their respective aquifers such as chemistry of the rock types, chemistry of precipitated water, and rate of evaporation (Gibbs, 1970). In the suggested diagrams, in which ratio of dominant anions and cations are plotted against the value of TDS. In the Gibbs diagrams, ratio 1 represents cations and ratio 2 indicates anions as a function of TDS. These diagrams are widely employed to assess the functional sources of dissolved chemical constituents, such as precipitation, rock, and evaporation dominance (Gibbs 1970).

Stiff diagrams are graphical representation of water chemical analyses, first developed by Stiff (1951). A polygonal shape is created from three or four parallel horizontal axes extending on either side of a vertical zero axis. Cations are plotted in milliequivalents per liter on the left side of the zero axis, one to each horizontal axis, and anions are plotted on the right side. Stiff patterns are useful in making a rapid visual comparison between water from different sources (Abbott, 2008). It helps visualize ionically related waters from which a flow path can be determined, if the flow path is known, to show how the ionic composition of a water body changes over space and/or time.

CHAPTER THREE

METHODOLOGY

3.1 SOURCE OF DATA

The data used for this study is secondary physico-chemical data obtained from the Community Water and Sanitation Agency, Central Region, Ghana. It consisted of a total of 40 boreholes; 6 from Assin North Municipal, 21 from Assin South and 13 from Twifo Hemang Lower Denkyira.

The physical parameters include pH, Electrical Conductivity (EC), Total Hardness (TH) and Total Dissolved Solids (TDS). The chemical parameters consist of major cations (sodium, potassium, calcium and magnesium) and major anions (chloride, sulphate, nitrate, and bicarbonate). Other physicochemical parameters (salinity indices) analysed include fluoride, Permeability Index (PI), Residual Sodium Carbonate (RSC) Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR).

3.2 DATA ANALYSIS

Groundwater quality assessment was carried out to determine the suitability of the water samples for domestic and agricultural (irrigation) purposes, and the assessment was primarily based on recommended permissible limits for certain parameters stated by Water Resource Commission (WRC, 2003) and World Health Organization (WHO, 2011b). The borehole stations have been re-coded to facilitate easy analysis and discussion. The boreholes from Twifo-Hemang Lower Denkyira District are coded T1 to T13. The group from Assin North District has codes from AN14 to AN19 whilst those with codes AS20 to AS40 are from the Assin South District.

Sodium Adsorption Ratio (SAR) was calculated using the following equation (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)}} \tag{3.1}$$

where all the ions are expressed in meq/L.

The Residual Sodium Bicarbonate (RSBC) was determined according to Gupta and Gupta (1987):

$$RSBC = HCO_3^{-} - Ca^{2+} \tag{3.2}$$

where, RSBC and the concentration of the constituents are expressed in meq/L.

The Permeability Index (PI) was estimated according to Doneen (1964) employing the following equation:

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100 \tag{3.3}$$

where, all the ions are expressed in meq/L.

The Magnesium Adsorption Ratio (MAR) was calculated using the following equation (Raghunath, 1987):

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \tag{3.4}$$

where, all the ionic constituents are expressed in meq/L.

Methods of Richards (1954) and Wilcox (1955) have been used to classify and understand the basic character of the chemical composition of groundwater, since the suitability of the groundwater for irrigation depends on the mineralization of water and its effect on plants and soil. Percent sodium can be determined using equation (3.5) by Richards (1954) as:

$$Na\,\% = \frac{Na + K}{Ca + Mg + Na + K} \times 100 \qquad (3.5)$$

where all cations are values given in mg/L.

Kelley's Ratio (KR) by Kelley (1963) is expressed as:

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \qquad (3.6)$$

with all ionic parameters expressed in meq/L.

To know the groundwater chemistry and the relationship of the chemical components of water to their respective aquifers such as chemistry of the rock types, chemistry of rain water, and rate of evaporation, Gibbs (1970) has suggested diagrams in which ratio of dominant anions and cations are plotted against the value of TDS. These ratios were determined using equations (3.7) and (3.8) by Gibbs (1970):

$$Ratio_{1} = \frac{Na^{+}}{Na^{+} + Ca^{+}} \qquad (3.7)$$

$$Ratio_{2} = \frac{Cl^{-}}{Cl^{-} + HCO_{3}^{-}} \qquad (3.8)$$

There are tools (computer based programmes) that are used in water quality analysis such as AquaChem v.2012.1. AquaChem is a fully-integrated software package developed specifically for graphical and numerical analysis of geochemical data sets (Bogdon, 2012). AquaChem features a powerful database that can be customized and configured to include an unlimited number of attributes per sample and a built-in database of inorganic chemicals that are commonly-used for geochemical analyses, calculations and plotting. AquaChem's graphical plotting techniques include Piper, Stiff, Schoeller, Wilcox, Gibbs diagrams (Bogdon, 2012). Other forms of data displayed consist of scatter graphs, frequency histograms, pie charts, among others.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 GENERAL HYDROCHEMISTRY

The data from field work and laboratory analysis of the various physico-chemical parameters of groundwater samples obtain from Community Water and Sanitation Agency (CWSA), Cape Coast for 40 borehole stations are shown in Table A1 (Appendix). The results of physico-chemical data analysis and summary are presented in Table 4.1 and Box and Whisker plot (Fig 4.1). These include pH, EC, TDS and TH, Na^+, K^+, $Ca^{2+}$and Mg^{2+}, HCO_3^-, SO_4^{2-}, Cl^- and NO_3^-, Fe^{2+}, Mn (trace metals), and other parameters such as TA, F^- and NO_3^-. All parameters are in milligrammes per litre (mg/L) except pH in pH units and EC in µS/cm. From the summary of the parameters in Fig 4.1, ‘series 1’ represents the 25th percentile whilst the ‘series 2’ indicates the 75th percentile. In general, it can be observed that the data set is highly variable with values in majority of the parameters slightly skewed towards the maximum values.

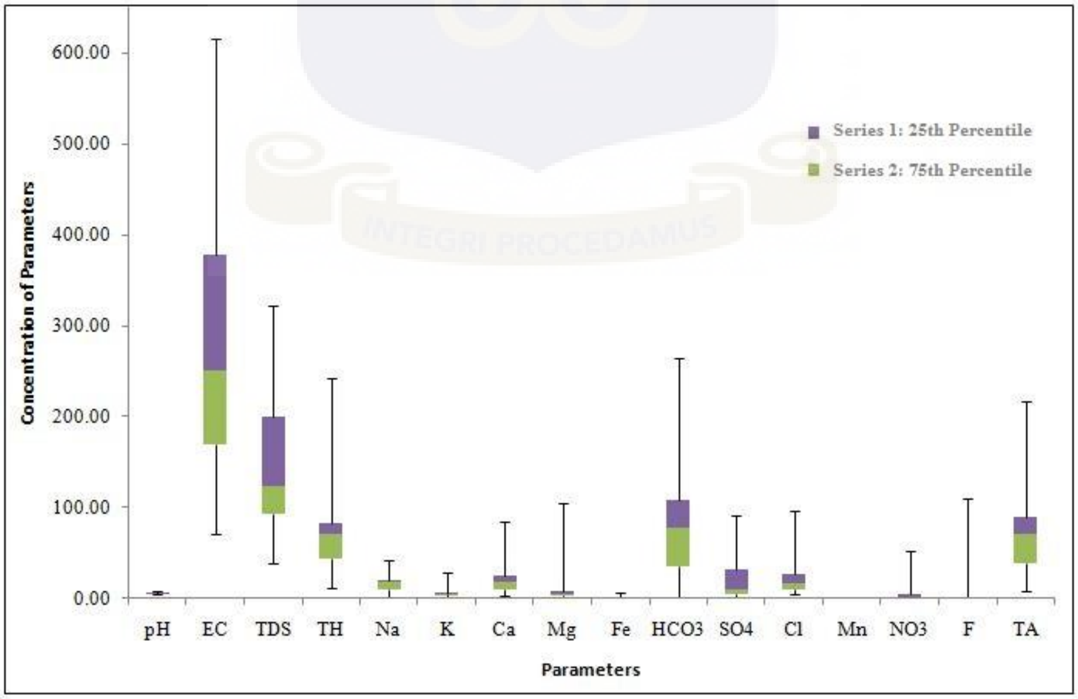

Fig 4.1: Box and Whisker plot showing the summary of Groundwater Quality Data

Table 4.1: Summary of Groundwater Quality Data

Parameters	Minimum	Maximum	Mean	Sta. Dev.
pH	4.91	7.7	6.3	0.7
EC	71.0	615.0	282.8	149.1
TH	12.0	242.0	75.7	54.3
TA	8.0	216.0	74.5	49.5
TDS	39.1	322.0	146.8	74.0
Na	0.0	41.5	17.2	10.5
K	0.0	28.5	5.4	4.2
Ca	3.2	85.0	20.5	16.8
Mg	1.0	104.0	8.8	16.5
Cl	5.0	96.0	22.3	18.5
SO_4	1.0	91.0	19.6	22.4
NO_3	0.2	52.0	5.2	9.7
HCO_3	0.0	264.0	80.1	66.5
F	0.1	110	5.2	19.6
Fe	0.0	6.0	1.1	0.7
Mn	0.0	1.1	0.2	0.2

4.2 GROUNDWATER QUALITY ASSESSMENT FOR DOMESTIC PURPOSES

Assessment of groundwater quality is undertaken to determine suitability of samples for domestic use (drinking, washing/bathing, and cooking). The potability of groundwater is mainly based on recommended permissible limits for parameters described by the Water Resource Commission (WRC, 2003) of Ghana, and World Health Organization (WHO, 2011b). Potable or ‘drinking’ water can be defined as the water delivered to the consumer that can be safely used for drinking, cooking, and washing (Zuane, 1997; WHO, 2011b). This assessment is done based on physical, chemical (cation and anions) parameters and trace metals.

4.2.1 Physical Parameters

The range of pH values of samples in the study area are from 4.9 (acidic) to 7.7 pH unit (slightly alkaline) with an average of 6.3 pH unit (Table 4.1). From this table, 25 samples of the groundwater had pH values below the acceptable lower limit of 6.5, as pH values less than 6.5 are considered too acidic for human consumption and can cause health problems such as acidosis (Ackah et al., 2011; WHO, 2011b). Table 4.6 has the list of these 25 samples. The acidic nature of most of the samples might be due to high level of calcium in the weathering of minerals such as carbonate, gypsum, feldspar making up the aquifers (Abdul-Razak, 2009). Other sources may include anthropogenic activities like sewage disposal and use of fertilizers in the highly populated coastal segment of the study area followed by natural phenomenon like intrusion of brackish water into the aquifers, which initiates the weathering process of underlain geology (WHO, 2011b).

The Electrical Conductivity (EC) values ranged between 71.0 and 615.0 µS/cm with mean value of 282.8 µS/cm (Table 4.2). The EC in water samples is an indication of dissolved ions in the sample and the very large variations in the study area may be attributed to variation in total dissolved solids. High EC is the result of ion exchange and solubilization in the aquifer system (Sanchez-Perez and Tremolieres 2003). The relatively high conductivities recorded in the area could be as a result of weathering of granite, which may increase the level dissolved substances in the water. This is augmented by domestic effluent discharges and surface run-off from the cultivated fields which might have increased the concentration of TDS (Bhat et al., 2013). There is no indication of adverse health effects associated with high electrical conductivity of water

(WHO, 2011b). However, since all the conductivity values are higher than the threshold of 45 µS/cm (WRC, 2003), a slight salty taste is expected in samples.

The Total Hardness (TH) in the samples range from 12 to 242 mg/L with average value of 75.7 (Table 4.2). From Table 4.3, the water samples are soft, lather easily with soap, and do not develop scales in water heaters and distribution pipes (WHO, 2011). Two samples indicate moderate hardness (150-200 mg/L) and 2 samples show hardness (200-300 mg/L). The water hardness classification by WHO (2011b) as shown in Table 4.3 and illustrated by Fig 4.2, are found to be below the maximum permissible limit of 500 mg/L for drinking water. The slight elevated levels of TH could be attributed to weathering of salt-bearing rocks (sulphate and chloride), with detergents and soaps aggravating the situation (Ananthakrishnan et al., 2012).

Table 4.2: Physical Parameters with permissible limits prescribed by WHO for drinking purposes

Parameters	Recommended Permissible Limit (WHO, 2011)	Amount in Samples	Number of Samples outside MPL
pH	6.5	4.9 – 7.7	25
EC	45	71 - 615	40
TH	500	12 – 242	0
TDS	1000	39.1 – 322	0

Table 4.3: Suitability of groundwater for washing/bathing based on Hardness (WHO, 2011b)

Total Hardness	Water Class	Number of Samples	Percentage
0 – 50	Soft	12	30.0
50 – 100	Moderately Soft	20	50.0
100 – 150	Slightly Hard	4	10.0
150 – 200	Moderately Hard	2	5.0
200 – 300	Hard	2	5.0
> 300	Very Hard	0	0.0

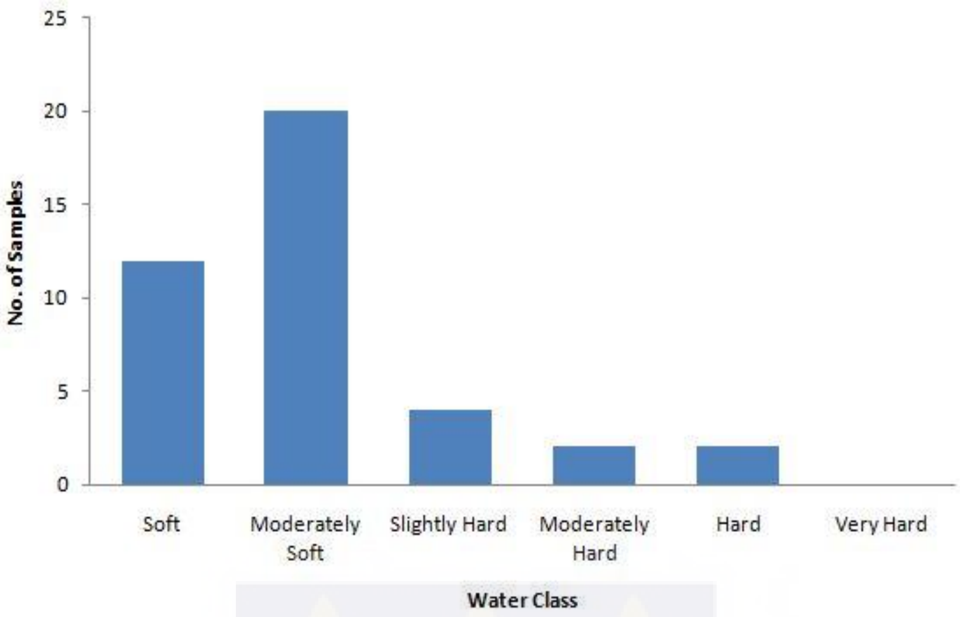

Fig 4.2: Suitability of groundwater for washing/bathing based on Hardness (WHO, 2011b)

The TDS concentration in the study range is between 39.1 and 322 mg/L with 146.8 mg/L as the average (Table 4.2). As shown in Table 4.5, all samples are fresh water types. The taste of water with a TDS level of less than about 600 mg/L is generally considered to be good (Ackah et al., 2011; WHO, 2011b). Drinking water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/L (WHO, 2011b). All the wells have TDS values below the most desirable limit value of 600 mg/L suggesting that samples are fresh water types (Tables 4.4) and therefore suitable for domestic chores.

Table 4.4 Classification of Groundwater domestic uses based on TDS (Fetter, 1990)

Total Dissolved Solids (mg/L)	Classification	Number of Sample	Percentage
0 – 1000	Fresh water type	40	100.0
1000 – 10000	Brackish water type	0	0.0
10000 - 100000	Saline water type	0	0.0

4.2.2 Correlation and Trend line Analysis

The major ions that contribute to the groundwater chemical budget are Na^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, and SO_4^{2-} (Chitradevi and Sridhar, 2011). The appraisal of Figs 4.3(a) and 4.3(c) reveal that Na^+ and Mg^{2+} produce 0.3 average correlation co-efficient (weak relationship and non-linearity) with TDS. This is an indication that these ions do not originate from the same source. An average correlation co-efficient of 0.8 was registered for TDS vs. Ca^{2+} which indicates strong relationship and linearity (Fig 4.3b). The average correlation co-efficient of 0.5, 0.5 and 0.6 are obtained for TDS vs. HCO_3^-, SO_4^{2-} and Cl^-, respectively, showing relatively low linearity. This suggests that in addition to hydrochemical contributions, other anthropogenic activities such as leachate and wastewater disposal among others may also be responsible for the variation in the chemical budget of the groundwater (Chitradevi and Sridhar, 2011). Trend line diagrams depicting these relationships are Figs 4.3(d), 4.3(e) and 4.3(c) respectively.

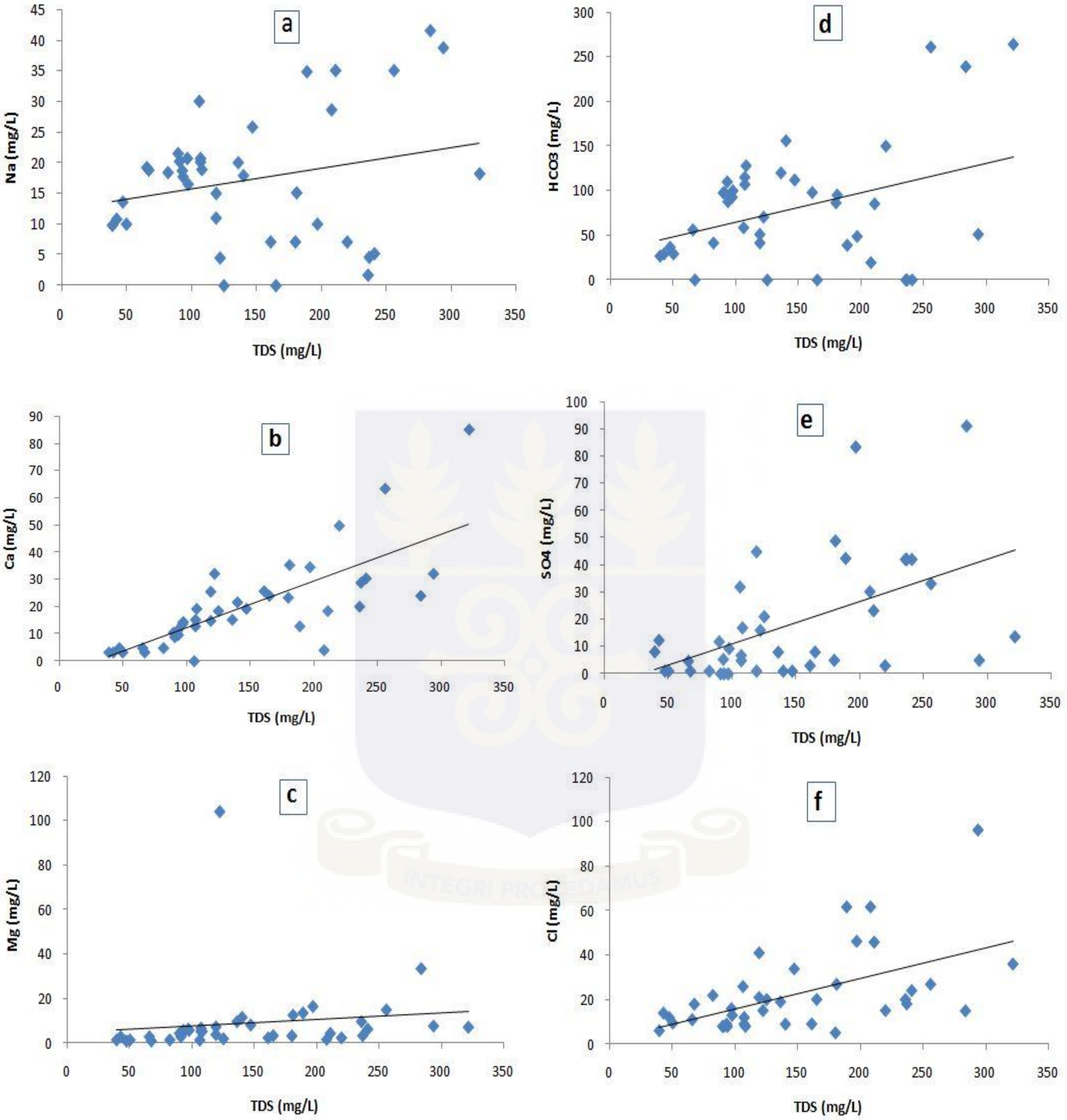

Fig 4.3: Cross Bi-plots showing correlation between TDS and Ions

4.2.3 Chemical Parameters and Trace Metal

Sodium and potassium are the most important ions occurring naturally in groundwater (Tikle et al., 2012). Whereas the concentration of Na^+ in the groundwater samples range from 0 to 41.5 mg/L with a mean value of 17.2 mg/L, that of K^+ vary from 0 to 28.5 mg/L, yielding an average value of 5.4 mg/L (Table 4.5). Cl^- concentration in the groundwater samples range from 5 to 96 mg/L with 22.3 mg/L as average whilst SO_4^{2-} has values ranging from 1.0 to 91 mg/L with 19.6 mg/L. The values of Na^+, K^+, Cl^- and SO_4^{2-} in all the samples are far below the WHO (2011b) maximum allowable limits of 200, 3000, 300 and 250 mg/L respectively in drinking water (Table 4.5).

In the current study, the majority of the samples show Na^+/Cl^- ratio greater than 1 and plot above the equiline (Fig 4.4a). This therefore suggests that weathering of silicate mineral (muscovite, feldspar, hornblende, mica, which are all present in the study area) is the dominant process responsible for the release of sodium in the groundwater. Other processes responsible for sodium in the samples may include dissolution of halite, seawater intrusion among others. A closer look at Fig 4.4e also reveals that the silicate weathering process accounts for the presence of K^+ in the water samples in the area while Cl^- and SO_4^{2-} contents in the groundwater samples could be as the result of dissolution of salt deposits, sulphate and gypsum-bearing sedimentary rocks (Lusczynski and Swarzenski, 1996).

The values of Ca^{2+} and Mg^{2+} range from 3.2 to 85 mg/L with an average of 20.5 mg/L and between 1 and 104 mg/L with mean of 8.8 mg/L (Table 4.5) respectively whilst the HCO_3^- values vary between 0 and 264 mg/L with 80.1 mg/L as average (Table 4.5). This shows that

HCO_3^- value in 2 of the samples (5%) exceeds the permissible limit of 240 mg/L (WHO, 2011b). The samples are AS33 and AS35 with their respective values of 264 and 261 mg/L. The high level of HCO_3^- is from the weathering process of carbonate mineral (calcite, dolomite, siderite, which are common in the study area), which can give drinking water unpleasant taste (Bhat et al., 2013). Ca^{2+} and Mg^{2+} register values far below the recommended limits of 200 and 200 mg/L (WHO, 2011b) respectively.

The scatter diagram of Ca^{2+}+Mg^{2+} vs. HCO_3^-+SO_4^2 (Fig 4.4d) shows that greater percentage of the samples plot above the equiline illustrating that carbonate weathering is the dominant process producing Ca^{2+} and Mg^{2+} to the groundwater (Bhat et al., 2013). Since HCO_3^- is the dominant anion (value higher than other anions in samples) in the groundwater of the study area, the elevated values recorded by the 2 samples (Table 4.6) may be attributed to availability of the carbonate minerals in the recharge area (Elango et al. 2003).

Table 4.5: Chemical Parameters with Permissible Limits prescribed by WHO for drinking purposes

Parameters	Recommended Permissible Limit (RPL)	Amount in Sample	Number of Samples outside RPL
Na	200	0 - 41.5	0
K	3000	0 - 28.5	0
Ca	200	3.2 - 85	0
Mg	200	1 - 104	0
Cl	300	5 – 96	0
SO_4	250	1 – 91	0
NO_3	50	0.2 – 52	1
HCO_3	240	0 – 264	2
F-	1.5	0.1 – 110	7
Fe	1	0 – 6	8
Mn	0.1	0 – 1.1	18

Again, Fig 4.4d suggests the contribution of cation exchange to be responsible for increase in the content of the alkaline earth elements (Ca and Mg) in groundwater from the aquifers. Majority of the samples plot toward the cation side of the equiline indicating excess of the alkaline earth elements (Yidana et al., 2011b). Also, the relationship between Na+K-Cl and Ca+Mg-HCO_3+SO_4 (Fig 4.4f) shows that the hydrochemical behavior of the major ions in groundwater is due to cation exchange processes. The Na+K-Cl ions represent the contribution of sources other than the dissolution of halite to the concentrations of Na^+ and K^+ in water. In other words, there is ion exchange of Na^+ and K^+ in water for Ca^{2+} and Mg^{2+} from rock (aquifer) (Bhat et al., 2013). That is more of the alkaline earth elements are released from the aquifer into the water while the alkali in the water are absorbed.

Nitrate (NO_3^-) has values between 0.2 and 52.0 mg/L and a mean value of 5.2 mg/L, with 1 of the samples registering a value of 52 which is above the WHO (2011) maximum permissible limit for drinking water (Table 4.5). The high value of NO_3^- indicated by well T11 (Table 4.7) may be as a result of the atmosphere and organic matter decomposition in the study area (Saleh et al., 1999; Yidana et al., 2011a). It could also be prevalent in the fertilizers (commonly urea, nitrate or ammonium compounds) that are used for agricultural practices in the study area, since most of the study area is largely agrarian (Subramani et al., 2005).

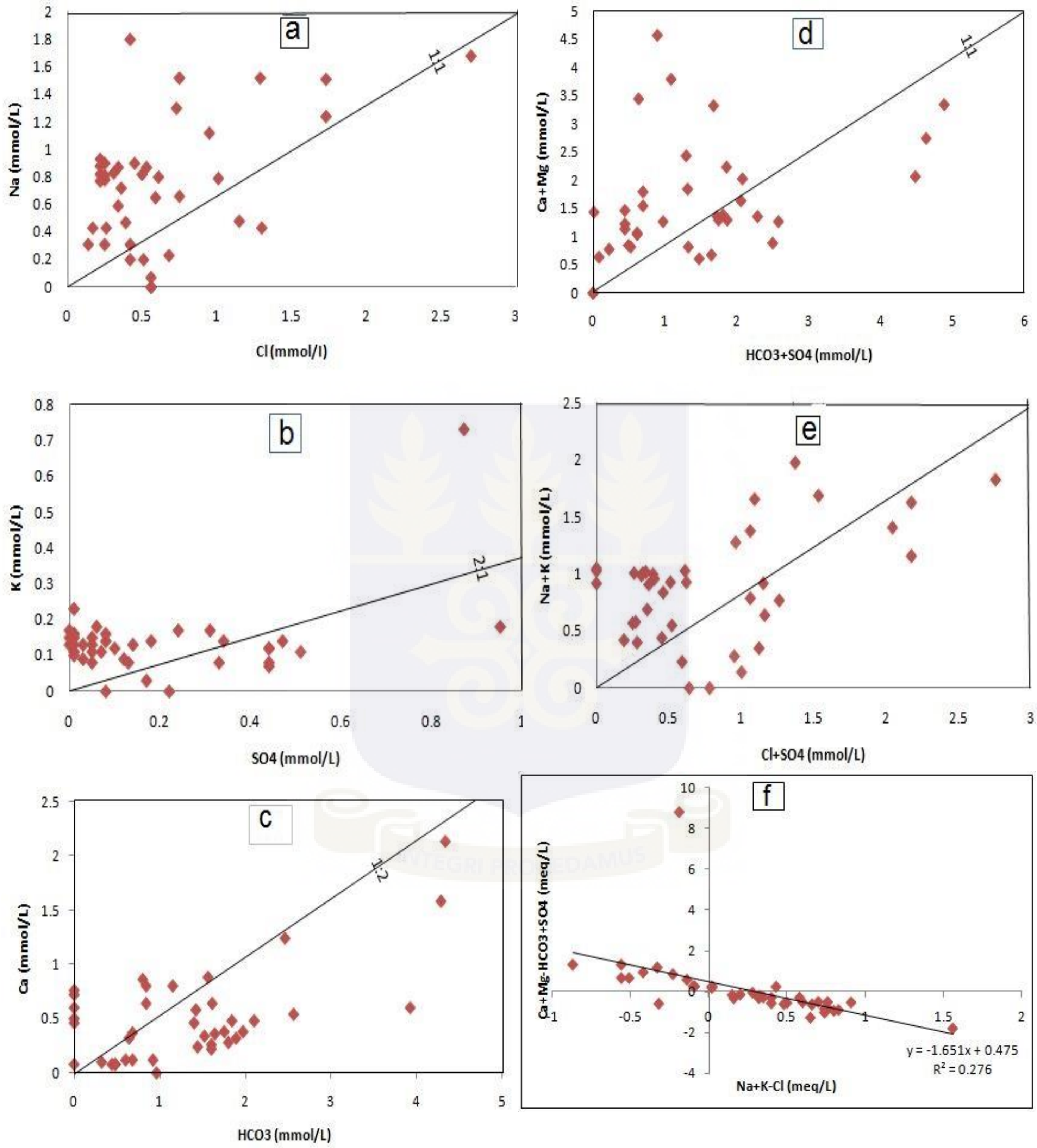

Fig 4.4: Scatter Plots representing Processes responsible for Hydrochemistry

The concentrations of Fluoride (F^-) in samples from the study area vary from 0.1 to 110 mg/L with an average value of 5.2 mg/L (Table 4.6). Seven samples (Table 4.7) are beyond the threshold of 1.5 mg/L (WHO, 2011b). Fluoride is one of the essential components, aside calcium, widely used in dental preparations to combat dental caries, particularly in areas of high sugar intake (WHO, 2011b). Studies across Ghana have shown that between 20-30% of borehole water have fluoride levels higher than 1.5 mg/L (WRC, 2003). The elevated level of F^- in the 7 samples may come from fluorspar (fluorite), amphiboles, apatite, cryolite, and mica found in the study area (Rahman, 2002; Viero et al., 2008). The increased values of fluoride in the samples may give protection against dental caries, and maintain normal development of healthy teeth and bones (Fawell et al., 2006). However, continuous consumption of these high concentrations can cause dental flourosis, and in extreme cases, even skeletal flourosis (Rao, 2006).

The range of values of the trace metals (Fe^{2+} and Mn) ranges between 0 and 6, and from 0 to 1.1 mg/L respectively (Table 4.5). Sources of these trace metals are mainly from weathering of carbonate rocks (limestone) which are widely distributed in the environment (Merian, 1991; O'Neil, 1993) but anthropogenic activities have augmented their level in the environment greatly (Prater, 1975; Sayyed and Sayadi, 2011). Eight of the samples (representing 20%) in the current study displayed elevated Fe^{2+} levels above the 1 mg/L maximum recommended limit of for drinking (WHO, 2011b). These samples are T11 (2.6), T12 (1.7), AS22 (1.1), AS25 (6.0), AS35 (1.1), AS36 (1.4) and AS39 (1.8). In the case of Mn, as many as 18 samples, representing about 45%, have values between 0.2 and 1.1 mg/L which are found to be above the WHO (2011b) recommended maximum allowable limit of 0.1 mg/L in drinking water and these samples are shown in Table 4.6. The sources of iron and manganese in the study area can be attributed to dissolution of limestone, sulphides, and oxidation of pyrite and arsenopyrite (iron-bearing rocks) (Obiefuna and Sheriff, 2010), and the presence of siderite and hydroxides (Suh, 2004). In addition, biotite and other varieties of granitic minerals such as muscovite and mica present in the study area may also contribute to the higher iron and magnesium levels in the samples (Leube et al., 1990)

4.2.4 Mechanisms Controlling Groundwater Chemistry

Groundwater is always interacting with minerals that form the aquifer, and this relationship has a significant influence on water quality (Cederstorm 1946; Gupta et al. 2008; Subramani et al. 2009). To know mechanisms controlling groundwater chemistry, Gibbs (1970) has proposed diagrams in which ratios of dominant cations and anions are plotted against TDS values. The values of the Gibbs ratios 1 and 2 used in plotting Fig 4.5 (Gibbs diagrams) are determined by equations (3.7) and (3.8) respectively. These diagrams are widely employed to assess the functional sources of dissolved chemical constituents, such as precipitation, rock, and evaporation dominance (Gibbs, 1970). From Fig 4.5, majority of the samples in the study area fall in the rock dominance section suggesting that chemical weathering is the dominant mechanism governing groundwater chemistry through dissolution of the rock forming minerals of the aquifer.

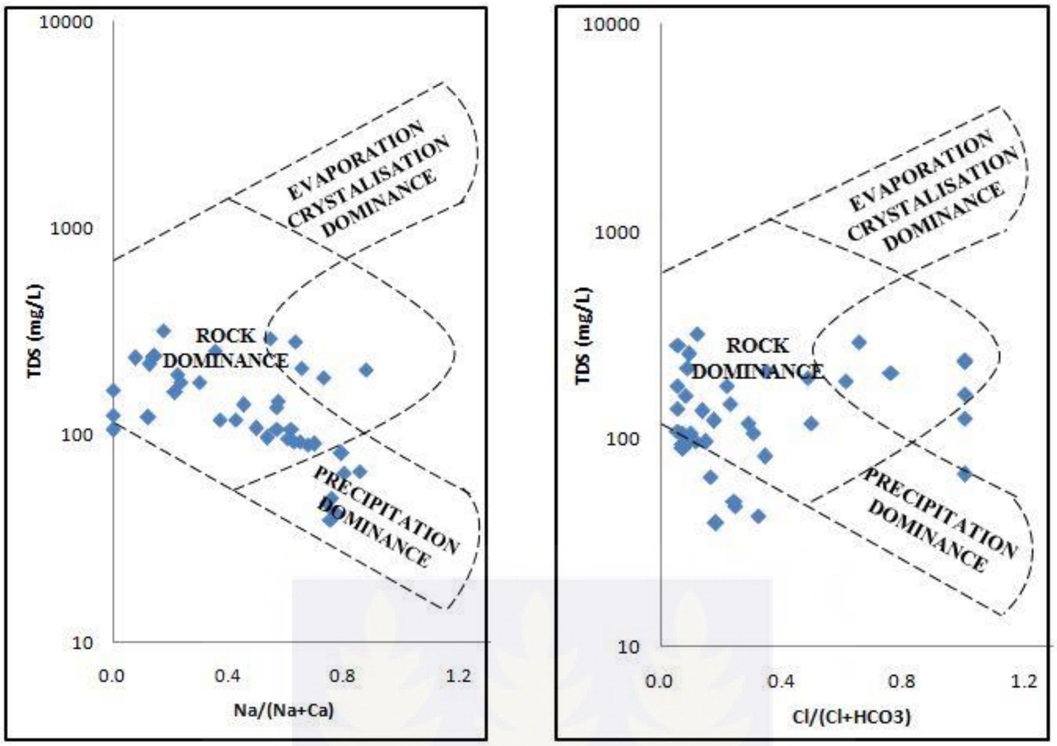

Fig 4.5: Gibbs diagram representing mechanisms governing groundwater chemistry (Gibbs, 1970)

4.2.5 Hydrochemical Facies of Groundwater

The values obtained from the physico-chemical analysis of groundwater samples revealed that the dominant cation in the area is Ca^{+} and the anion is HCO$_3^{-}$. The dominant presence of ions in the study area is in the order; Ca^{2+}>Na^{+}>Mg^{2+}>K^{+}:HCO$_3^{-}$>SO$_4^{2-}$>Cl^{-}. Chemical data of the study area are presented in a Piper Trilinear diagram (Fig 4.6). An appraisal of the diagram shows that considerable number of the samples falls in the Ca-Mg cation zone while the dominance of HCO$_3$-Cl type of water can be observed among the anions. From Fig 4.6, fields 1, 3 and 4 contain 52.5%, 12.5% and 12.5% of samples in the studied area respectively, which indicate that majority of samples, are of Ca-HCO$_3$ type followed by Mixed Ca-Na-HCO$_3$ type and Mixed Ca-Mg-Cl type. It is indicative therefore that the general groundwater type dominating the study area is Ca-HCO$_3$. This also suggests that throughout the study area alkaline earth elements (Ca^{2+}

and Mg^{2+}) dominate over alkali (Na^{+} and K^{+}) and weak acid (HCO$_3^{-}$) dominate over strong acids (Cl^{-} and SO$_4^{2-}$) in the groundwater.

The Stiff diagram (Fig 4.7) shows that water samples obtained from T stations gave rise to Na-Ca-Mg-HCO$_3$ (Fig 4.7a) groundwater type, whereas those from category AN and AS stations produced Ca-Mg-SO$_4$-Cl (Fig 4.7b) and Ca-Mg-Na-HCO$_3$ (Fig 4.7c) water types respectively. This further buttresses the result that the dominant cation, anion and water type in the current study is Ca^{+}, HCO$_3^{-}$ and Ca-HCO$_3$ respectively.

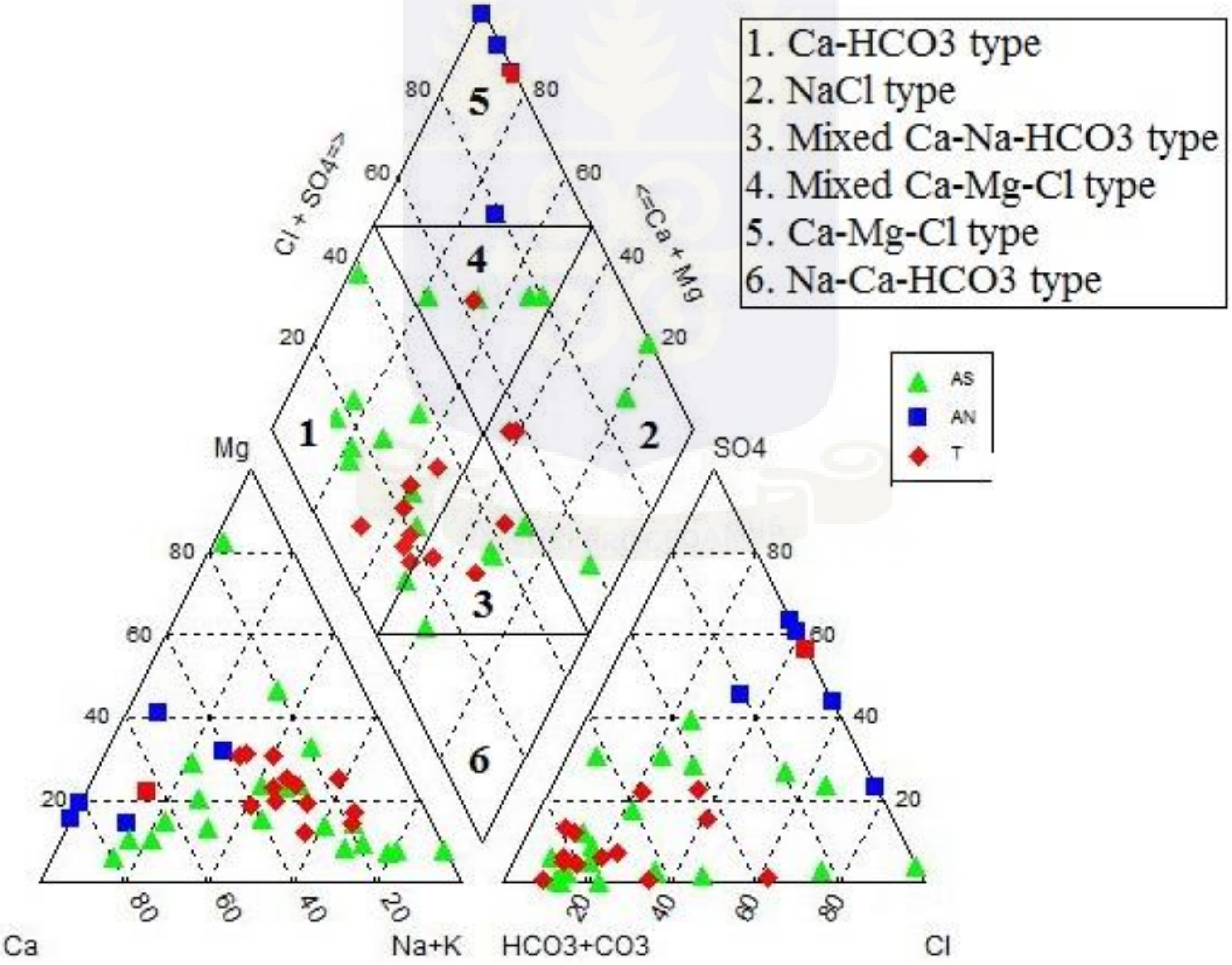

Fig 4.6: Hydrochemical Facies of groundwater in Piper Trilinear diagram (Piper, 1944)

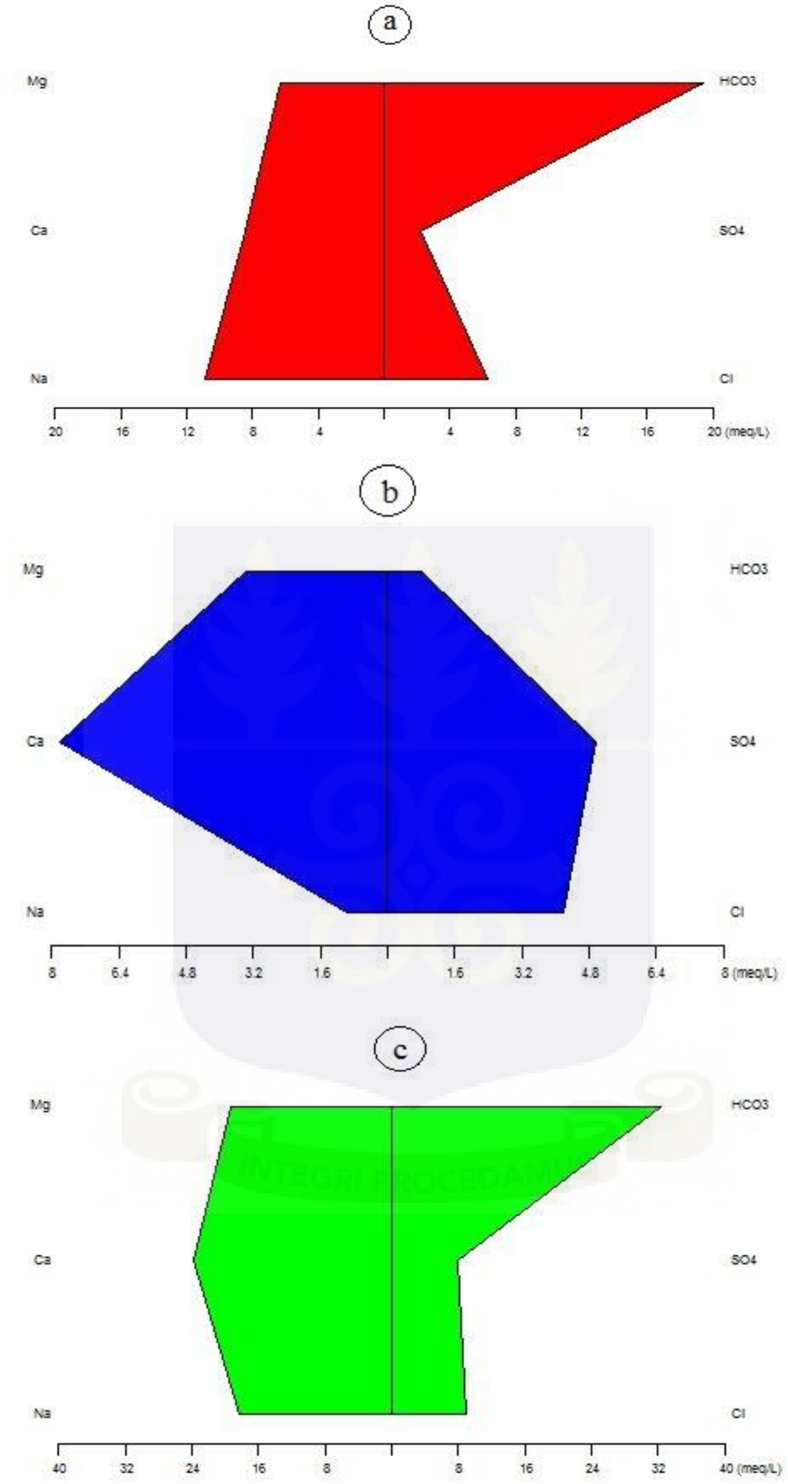

Fig 4.7: Stiff diagrams illustrating water types of T: Na-Ca-Mg-HCO_3, AN: Ca-Mg-SO_4-Cl and AS: Ca-Mg-Na-HCO_3 Stations (where T = Twifo Hemang Lower Denkyira, AN = Assin North and AS = Assin South)

Table 4.6: Samples in the study area outside Recommended Permissible Limit (WHO, 2011b)

Parameter	WHO (2011) RPL	Samples outside RPL
pH	6.5	T1 – T11, T13, AS25, AS26, AS28 – AS32, AS34, AS36 – AS40
HCO_3	240	AS33 and AS35
NO_3	50	T11
F	1.5	T11, AS21, AS22, AS23, AS24, AS25 and AS35
Fe	1	T11, T12, AS22, AS25, AS35, AS36 and AS39
Mn	0.1	T2, T4, T5, T7 - T10, AS25 - AS33, AS35 and AS39

4.3 GROUNDWATER EVALUATION FOR IRRIGATION PURPOSES

Salinity and indices such as, sodium absorption ratio (SAR), sodium percentage (%Na), residual sodium bicarbonate (RSBC), magnesium adsorption ratio (MAR), and permeability index (PI) are important parameters for assessing the suitability of groundwater quality for agricultural uses (Gowd, 2005; Raju, 2006). Electrical Conductivity (EC) and sodium (Na^+) also play a vital role in determining the suitability of water for irrigation. Higher EC in water creates harmful effects of irrigation water increasing with the total salt concentration, irrespective of the ionic composition of the soil. Higher salt content in irrigation water causes an increase in soil solution osmotic pressure (Thorne and Peterson, 1954). Apart from affecting the growth of plants, the salt also affect the soil structure, permeability and aeration. All the calculated salinity indices values presented in Table A2 (Appendix) are expressed in milliequivalent per litre (meq/L) except values of TDS and TH which are in mg/L and EC in µS/cm.

Table 4.7: Summary of Salinity Indices of Samples

Parameter	SAR	RSBC	KR	PI	MAR	Na%	TDS	TH	EC
Minimum	0.0	-1.5	0.0	0.0	7.4	0.0	39.1	12.0	71.0
Maximum	3.0	2.7	3.7	156.0	84.3	80.6	322.0	242.0	615.0
Mean	1.0	0.3	0.8	83.4	37.7	39.5	147.9	76.5	285.1
Sta. Dev.	0.7	0.9	0.8	44.4	16.3	22.0	74.7	54.8	150.3
Sum	38.9	11.5	31.6	3251.9	1469.3	1539.6	5766.1	2984.0	11120.0

EC and SAR usually combine to indicate the salinity level of water. SAR is defined by Richards (1954) in equation (3.1), with all parameters expressed in meq/L. In this work, the values of SAR range from 0 to 3.0 meq/L, while EC values vary between 71 and 615 μS/cm (Table 4.8). The relationship between SAR (sodium hazard) and EC (salinity hazard) in groundwater samples of the study area is plotted in the USSL diagram (Fig 4.8) of irrigation water classification. Based on the USSL diagram, the water quality shows that 4 samples fell within the C1-S1 (low salinity and sodium) indicating excellent irrigation water, 12 samples falling into C2-S1 (medium salinity and low sodium) category representing excellent to good irrigation water, and categories C1-S2 and C2-S2 showing 9 and 4 samples respectively. Samples falling into these categories can be used for irrigation without any adverse effects on the physical properties of the soil. Water samples that fell into categories C1-S3 and C2-S3 may be used for irrigation but not without soil management practices. The sample in C2-S4 (medium and very sodium) category is not appropriate for irrigation on all types of soil since it poses the danger of exchangeable sodium. The source of the soaring concentration of Na^+ in the sample can be adduced to the weathering of silicate mineral as stated earlier, and this can be fatal to irrigated crops without proper attention. Even if the salinity is low, high concentrations of the Na^+ in these samples can interfere with the ability of plants to absorb water from soils (Yidana et al., 2011b). The long term effect of using the high Na^+ waters for irrigation is the accumulation of salts in the soils, leading to a reduction in the hydraulic properties of irrigation soils with time (Saleh et al., 1999). When this happens, the ability of such soils to support optimum plant growth and development is greatly affected.

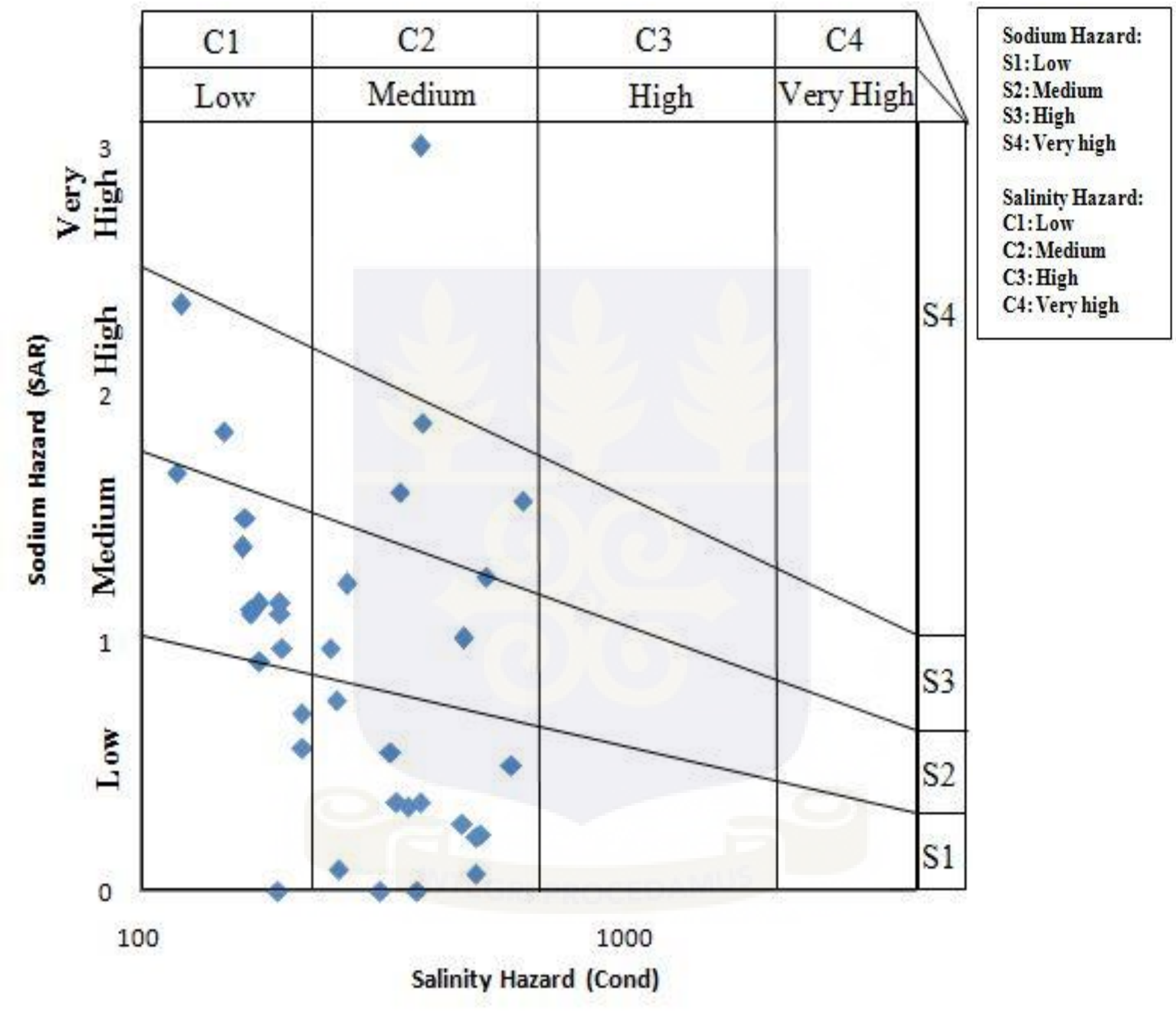

Fig 4.8: USSL Salinity Diagram showing classification of water quality for irrigation (Richards, 1954)

The estimation of the RSBC concentration in the studied samples using equation 3.2 (Gupta and Gupta, 1987) yielded values ranging from -1.5 to 2.7 meq/L (Table 4.8). Groundwater quality for irrigation based on RSBC is shown in Table 4.8 with 35 samples (87.5%) being safe for agricultural purposes. It can also be seen that 4 samples and 1 sample are moderately suitable and unsuitable respectively for agriculture. The excess RSBC in sample AS27 with a value of 2.7 meq/L is as a result of weathering carbonate minerals such as calcite, dolomite and siderite. It is considered to be detrimental to the physical properties of soils that are used, as it causes dissolution of organic matter in the soil which in turn leaves a black stain on the soil surface (deposition of sodium carbonate) on drying (Obiefuna and Sheriff, 2010; Ahamed et al., 2013). Fig 4.9 is a line graph depicting irrigation water classification based on RSBC.

Table 4.8: Groundwater quality for irrigation based on RSBC

RSBC (meq/L)	Water Categories	Number of Samples	Percentage of Samples
<1.25	Safe	35	87.5
1.25 – 2.5	Moderately Suitable	4	10
>2.5	Unsuitable	1	2.5

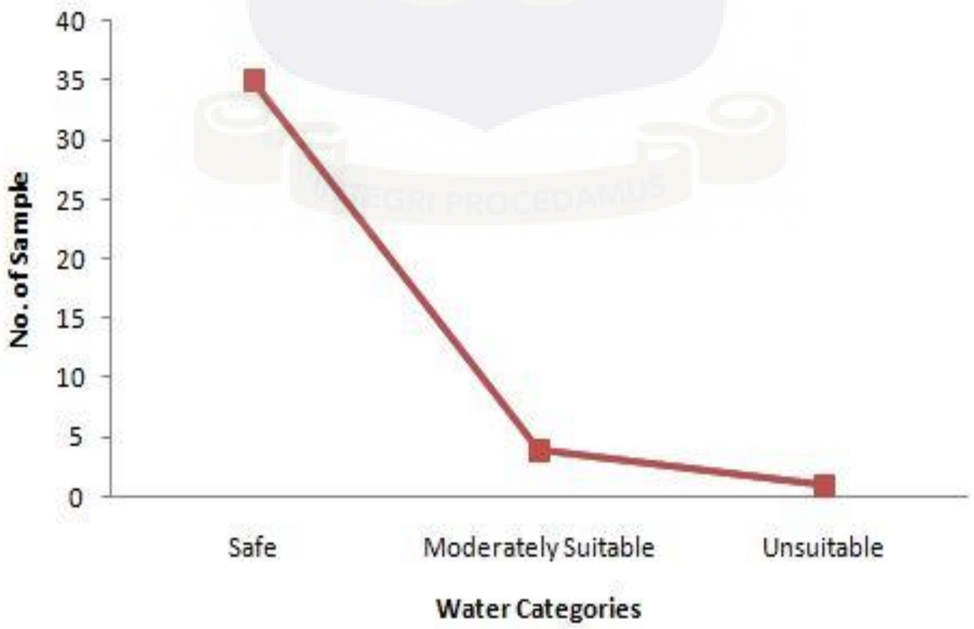

Fig 4.9: A line graph of Groundwater quality for irrigation based on RSBC

Permeability Index (PI) was estimated by employing equation (3.3) where, all ions were expressed in meq/L (Doneen, 1964). The PI values for the study area vary between 0 and 156 meq/L (Table 4.7). The permeability of the soil is affected by the long term use of water influenced by Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- (Raghunath, 1987). According to Doneen's chart (Doneen, 1964), irrigation water is classified as Class I, Class II, and Class III. From Table 4.9 and Fig 4.10, Classes I and II have 23 samples and 11 samples which indicate that the waters are good and acceptable for irrigation respectively. Six samples on the other hand fall into Class III, and these waters are unacceptable for irrigation (Doneen, 1964; Yidana et al., 2010).

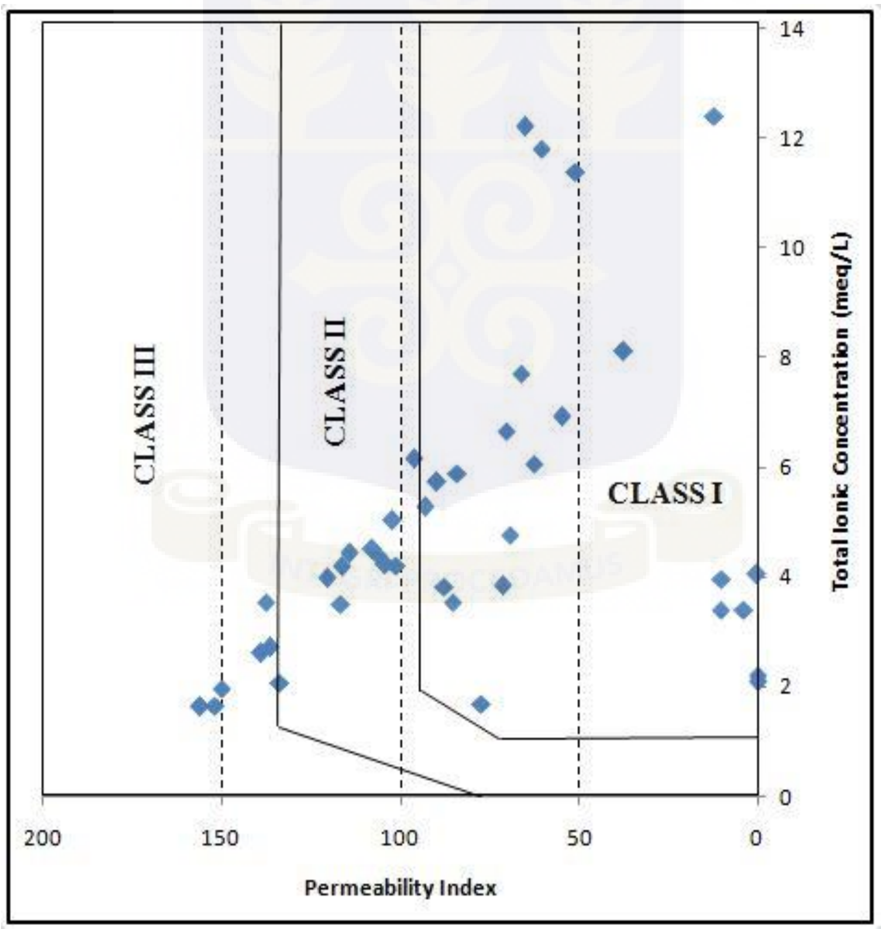

Fig 4.10: Doneen's Chart showing water quality for irrigation based on PI (Doneen, 1964)

Table 4.9: Groundwater quality for irrigation based on Permeability Index

PI vs. Total Ionic Concentration (%)	Water Classes	Categories	Number of Samples
>75	Class I	Good	23
50 – 75	Class II	Acceptable	11
<25	Class III	Unacceptable	6

Table 4.10: Irrigation Water Quality Classification based on MAR

MAR (%)	Water Class	Number of Samples
<50	Suitable	35
>50	Unsuitable	5

The values of Magnesium Adsorption Ratio (MAR) in the study area ranges between 7.4 and 84.3% (Table 4.7). It was calculated using the equation (3.4) where all ionic concentrations were expressed in meq/L (Raghunath, 1987). According to Ishaku et al. (2012), water with MAR values of <50% is suitable for irrigation, while more >50% MAR is unsuitable for irrigation practice. Based on this classification, Table 4.10 illustrates that 35 (87.5%) of samples are suitable whereas 5 (12.5%) of the samples are unsuitable for irrigational practice. Magnesium content of water is considered as one of the most important qualitative criteria in determining the quality of water for irrigation (Hem, 1985). Continuous use of water from these high magnesium content boreholes like those in Table 4.13 could adversely affect crop yield as soils properties may be affected (Joshi et al., 2009). The elevated values can be adduced to the dominance of alkaline earth elements over alkali during the cation exchange process.

The values of Percentage Sodium (%Na) in groundwater samples in the study area vary between 0 and 80.6% (Table 4.7). Percentage Sodium was computed with respect to the relative proportions of cations present in water with equation (3.5) espoused by Richards (1954). Figure 4.11 is a Wilcox diagram illustrating the different classes of water quality for irrigation. It can be observed that the high concentration of sodium relative to the total cation contents group is also characterized by low salinity. Accordingly, 97.5% (39) of water samples are 'excellent to good' for irrigation while 1 sample falls within 'permissible to doubtful' for irrigation category. Excess Na^+, combined with carbonate, leads to the formation of alkali soils, whereas with chloride, saline soils are formed. Neither the alkali soils nor saline soils will support plants growth (Rao, 2006).

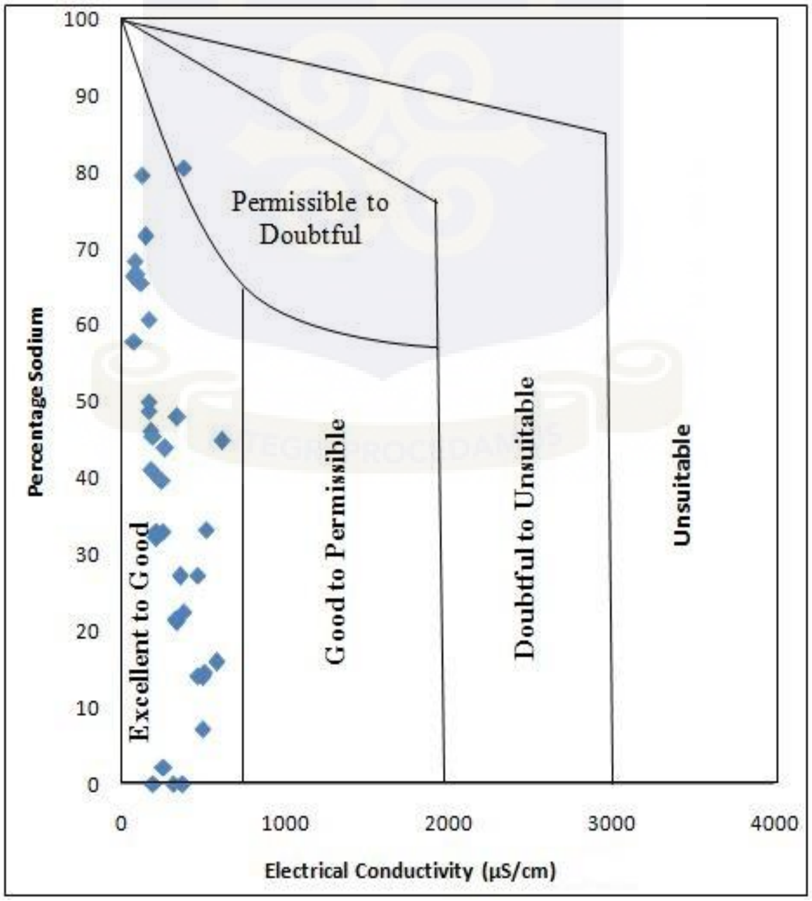

Fig 4.11: Classification of Irrigation water quality based on Na% and EC (Wilcox, 1955)

The Kelley Ratio (KR) values determined for the study area range between 0 and 3.7 meq/L. Sodium measured against Ca^{2+} and Mg^{2+} is considered by Kelley (1963) for calculating KR using the equation (3.6) where, all the ions are expressed in meq/L. Table 4.7 reveals that 10 samples fall outside the permissible limit of 1.0 and are considered unsuitable for irrigation purposes. These samples are included in Table 4.12. This indicates that most of the studied groundwater samples however, have KR within the permissible limit of 1.0 and are therefore considered suitable for irrigational practice. The increased presence of Ca^{2+} and Mg^{2+} in the groundwater is responsible for low values of KR in the study area.

The TDS in the water samples of the study area has values ranging from 39.1 to 322 mg/L (Table 4.7). Table 4.11 represents the nature of TDS in the water samples. All the values are less than 1000 mg/L and are within the nonsaline category, and are therefore classified as excellent irrigation waters (Robinove et al., 1958). Obiefuna and Sheriff (2011) state that high levels of TDS in the form of salts of calcium, magnesium, sodium and potassium present in irrigation water poses dangers to the health of plants. With this, salts from the major ions when present in excess quantities can affect the osmotic activities of the plants and may prevent adequate aeration.

Table 4.11: Range of TDS for irrigation use (Robinove et al., 1958)

TDS (mg/L)	Classification	Number of Samples
<1000	Non saline	40
1000 – 3000	Slightly saline	0
3000 – 10000	Moderately saline	0
>10000	Very saline	0

Table 4.12: Samples in the study area outside Recommended Permissible Limit (where T.I.C = Total Ionic Concentration)

Irrigation Indices	Recommended Permissible Limit	Samples outside RPL
RSBC	2.5 meq/L	AS27
PI vs. T.I.C	25% min.	AN15 - AN20
MAR	<50%	T7, T8, AS20, AS27 and AS34
KR	1.0	T2, T5, T8, T13, AS24, AS26, AS29-AS32

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The analyses and evaluation of the hydrochemical data of groundwater samples for domestic purposes per WHO (2011b) permissible limits reveal that the groundwater in the study area is generally fresh, soft to hard, and acidic to alkaline in nature, based on TDS, TH and pH. In general, from correlation and trend analysis, all cations except Ca^{2+} show very weak and non-linear relationship with TDS. Ca^{2+} has a co-efficient of 0.8 with TDS which indicate strong relationship and linearity.

The sum of Ca^{2+} concentration in the study area is relatively higher as compared to Mg^{2+}, Na^{+} and K^{+} concentrations. All the major cations (Na^{+}, K^{+}, Ca^{2+} and Mg^{2+}) registered values far below their respective recommended limits of 200, 3000, 200 and 200 mg/L. for the anions, the values of Cl^{-} and SO_4^{2-} in all the samples are far below the WHO (2011b) maximum allowable limits of 300 and 250 mg/L respectively in drinking water. HCO_3^{-} on the other hand has 2 of the samples (5%) exceeding the permissible limit of 240 mg/L. These samples are AS33 and AS35 with their respective values of 264 and 261 mg/L.

In the study, majority of the samples show that Na^{+}/Cl^{-} and K^{+}/SO_4^{2-} ratios are greater than 1, and Na^{+} and K^{+} values plot above the equiline. This therefore suggests that the weathering of muscovite, feldspar, hornblende, and mica is the dominant process responsible for the release of Na^{+} and K^{+} in the groundwater while Cl^{-} and SO_4^{2-} contents in the groundwater samples could be from dissolution of salt deposits, sulfate and gypsum-bearing sedimentary rocks. The scatter diagram of Ca^{2+}+Mg^{2+} vs. HCO_3^-+SO_4^{2-} shows that carbonate weathering is the dominant process producing Ca^{2+} and Mg^{2+} in the groundwater. The plot of Na+K-Cl vs. Ca+Mg-HCO_3+SO_4 shows that the hydrochemical behavior of the major ions in groundwater is also due to cation exchange processes. The Na+K-Cl ions represent the contribution of sources other than the dissolution of halite to the concentrations of Na^+ and K^+ in water. In other words, there is ion exchange of Na^+ and K^+ in water for Ca^{2+} and Mg^{2+} in the aquifer.

The sample T11 has nitrate (NO_3^-) value of 52 mg/L which is above the maximum permissible limit for drinking water while seven samples have F^- contents beyond the threshold of 1.5 mg/L. Eight of the 40 samples in this study display elevated Fe^{2+} levels above the maximum 1 mg/L recommended limit for drinking. In the case of Mn, as many as 18 samples have values between 0.2 and 1.1 mg/L, which are found to be above the recommended maximum allowable limit of 0.1 mg/L in potable water. Some of these samples include T2, T4, T9, AS25, AS27 and AS33 among others. The high levels of iron and manganese can attributed to the dissolution of limestone, sulphides, siderite, hydroxides and oxidation of pyrite and arsenopyrite.

The sequence of the abundance of the major ions is in the following order: $Ca^{2+}>Na^+>Mg^{2+}>K^+$ and $HCO_3^->SO_4^{2-}>Cl^->NO_3^-$. The alkaline earths exceed alkali metals and weak acidic anions exceed strong acidic anions with the dominant cation and anion being Ca^{2+} and HCO_3^- respectively throughout the study area. In the study area, the dominant hydrochemical facies of groundwater is Ca-HCO_3. Gibbs diagrams shows that majority of the samples in the study area fall in the rock dominance section suggesting that chemical weathering is the dominant mechanism governing groundwater chemistry through dissolution of the rock-forming minerals of the aquifer.

US salinity diagram illustrates that Water samples that fell into categories C1-S3 and C2-S3 may be used for irrigation but not without soil management practices. Based on RSBC 1 groundwater sample is unsuitable for irrigation purpose. Six samples fall into Class III of PI classification of irrigation water and these waters are unacceptable for irrigation.

According to MAR water classification, 35 samples are suitable whereas 5 samples are unsuitable for irrigational purposes. The values of TDS from the water samples of the study area have values far less than 1000 mg/L, and hence are within the non-saline class, and are said to be excellent for irrigation. In general, except the samples indicated in Tables 4.6 and 4.13 groundwater in the study area is suitable for domestic and irrigational purposes.

5.2 RECOMMENDATION

The study recommends that the District Assembly and other stakeholders in the water delivering sector should provide proper sanitary facilities in the study area, prevent leachate from septic tanks and landfills, and oxidation of nitrogenous waste products in human excreta as the result of people defecating indiscriminately. Appropriate water treatment methods should be provided in the area to improve the quality of water for the dwellers. There is the need to educate the public on efficient water use methodologies and the intensification of the educational awareness as to how to handle and locally treat water for domestic use. Shallow wells in intensive agricultural areas and septic field should be avoided.

From the analyses, it can be observed that, the groundwater resource from T11 well of the Twifo Hemang Lower Denkyira District is general not suitable for domestic purposes, as it is found out to be outside the recommended permissible limit (WHO, 2011b) in terms of pH, HCO_3^-, F^- and Fe^{2+} for matter should not be used at home, but can be used for irrigation. All samples in the Assin North Municipal are excellent for domestic and irrigation utilization. However, management practices are to be adopted to prevent soils in these from experiencing permeability problem, since samples have PI vs. T.I.C to be less than 25%. The borehole with ID number AS35 (Assin South Municipal) should be abandoned for domestic purposes, as the sample shows elevated values in HCO_3^-, F^-, Fe^{2+} and Mn. The use of agro-chemicals such as nitrogenous fertilizers poses a future threat to groundwater quality in the Assin South Municipal. Hence the Agricultural Extension Officers in collaboration with the various district administrators should institute measures to encourage the use of organic manure.

Farmers should be advised on the site selection and drilling of the wells for irrigation. Groundwater utilization and management policies should be formulated and implemented to overcome future conflict in utilization of the groundwater resource in the area and also to maintain the quality of the water.

District Assemblies, bilateral and multilateral organisations should not only drill wells for the communities and leave them for the community to manage but should be monitoring units of trace metal (Fe^{2+} and Mn) levels in such boreholes regularly for early detection of higher levels for possible corrective measures to be taken to avoid hazards. A simple remedy for Fe^{2+} and Mn could be water treatment with chlorine, ozone or by adding chemicals that cause the metals to form a solid that will settle or be filtered out.

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APPENDIX

Table A1: Physicochemical Parameters of the Study Area

Sample ID	pH	EC	TDS	TH	Na	K	Ca	Mg	Fe	HCO$_3$	SO$_4$	Cl	Mn	NO$_3$	F	TA
T1	6.23	195	107	60	20.7	4.3	12.8	6.8	0.445	115	6.76	8.9	0.03	0.729	0.209	94
T2	6.28	384	211	64	35	6.5	18.4	4.4	0.039	85.4	23.2	45.7	0.122	1.48	0.102	70
T3	6.32	163	89.7	44	21.5	3.5	10.4	4.4	0.076	97.6	11.8	7.9	0.042	1.57	0.563	80
T4	5.84	195	107	60	20.1	5.2	15.2	5.3	0.199	107	4.87	11.9	0.471	3.43	0.288	88
T5	5.39	71	39.1	14	9.8	5.6	3.2	1.5	0.913	26.8	8.09	6	0.366	2.72	0.412	22
T6	6.12	197	108	70	18.9	5.5	19.2	5.3	0.031	128	16.9	7.9	0.081	<0.001	0.388	100
T7	6	248	136	78	20	6.4	15.2	9.7	0.396	120	7.98	18.9	0.211	0.74	0.555	98
T8	5.47	77	42.4	20	10.8	3.3	3.2	2.9	0.012	29.3	12.3	13.9	0.113	0.623	0.551	24
T9	6.41	254	140	102	17.9	9	21.6	11.6	0.892	156	1	8.9	0.3	0.633	0.85	128
T10	5.86	267	147	82	25.8	6.2	19.2	8.2	0.117	112	1	33.7	0.218	14.7	0.823	92
T11	6.35	169	92.9	90	18.7	7.2	11.2	5.8	2.57	110	5.31	8.9	<0.001	52	110	28.1
T12	6.64	217	119	82	11	6.2	14.8	7.3	1.7	41.5	1	40.9	0.061	0.484	0.85	34
T13	5.68	119	65.5	24	19.2	3.3	4.8	2.9	<0.01	56.1	4.64	10.9	0.01	5.06	0.43	46
AN14	7.04	358	197	154	10	28.5	34.5	16.5	0.092	48.8	83.3	46.1	0.109	0.769	<0.005	40
AN15	6.72	494	236	50	1.7	2.9	20	9.7	0.2	0	42	20	0.002	0.22	0.65	68
AN16	6.85	505	241	76	5.2	4.5	30.4	6.3	0.4	0	42	24	0.003	0.35	0.7	66
AN17	6.89	496	237	72	4.6	3	28.8	3.4	0.2	0	42	18	0.03	0.6	0.65	70
AN18	6.99	374	165	74	0	0	24	3.4	0.1	0	8	20	0.009	0.25	0.55	136
AN19	7.05	314	125	54	0	0	18.4	2	Trace	0	21	20	0	0.28	0.6	74
AS20	7.32	257	122	12	4.5	1.3	32.1	104	0.12	70.4	16	15	0	<0.001	0.848	57.7
AS21	7.67	462	220	134	7.1	5.2	49.7	2.4	0.63	150	3	15	0	0.7	2.89	123
AS22	7.07	380	180	72	7.1	4.1	23.3	3.3	1.12	86.5	5	5	0	0.6	2.84	71
AS23	7.22	339	161	74	7.1	3.5	25.7	2.4	0.28	98	3	9	0	<0.001	2.84	80.3
AS24	6.51	615	294	112	38.7	5.7	32.1	7.7	0.5	51.2	5	96	0	17.3	2.22	42
AS25	5.68	122	67.1	12	18.8	4.2	3.2	1	6.02	0	1	17.9	1.09	10.3	31.7	8
AS26	5.61	149	81.9	18	18.4	5	4.8	1.5	0.447	41.5	1	21.8	0.401	4.15	0.191	34
AS27	6.98	517	284	198	41.5	7.1	24	33.5	1.02	239	91	14.9	0.441	0.612	1.37	196
AS28	5.61	216	119	82	15	5.3	25.5	3.9	0.093	51.2	44.8	20.9	0.102	0.793	0.909	42
AS29	5.45	85.7	47.1	16	13.6	4	4.8	1	0.272	36.6	1	11.9	0.243	2.56	<0.005	30
AS30	5.39	90.3	49.9	14	10	5.7	3.2	1.5	0.093	29.3	1	9.4	0.124	4.38	<0.005	24
AS31	5.92	165	90.8	34	20.2	6.8	8.8	2.9	0.04	97.6	<1	7.9	0.119	1.57	<0.005	80
AS32	4.91	378	208	80	28.6	6.8	4	1.7	0.075	19.5	30.2	61.5	0.116	5.76	<0.005	16
AS33	7	585	322	242	18.2	5.1	85	7.2	0.113	264	13.6	35.9	0.296	<0.001	0.519	216
AS34	5.47	344	189	88	34.8	4.8	12.8	13.6	0.039	39	42.4	61.5	0.031	9.32	0.146	32
AS35	6.93	466	256	220	35	5.6	63.3	15	1.05	261	33.1	26.8	0.474	2.1	1.57	214
AS36	6.06	176	96.8	60	20.7	5.1	13.6	6.3	1.35	92.7	<0.001	15.9	0.069	26.1	1.45	76
AS37	6.15	177	97.4	60	16.5	4.6	14.4	5.8	0.032	100	9.31	12.9	0.031	1.86	0.528	82
AS38	6.08	329	181	140	15.1	4.1	35.3	12.6	0.032	95.2	48.8	26.8	0.021	6.03	<0.005	78
AS39	6.04	170	93.5	46	17.7	5.9	9.6	5.3	1.84	87.8	<0.001	7.9	0.112	5.87	1.04	72
AS40	5.61	193	106	42	30	3.3	14.4.	1.4	0.022	58.6	31.9	25.8	0.062	1.17	<0.005	48

Table A2: Parameters used for the evaluation of Groundwater Quality for Irrigation Purpose

Sample ID	SAR	RSBC	PI	MAR	Na%	KR	TDS	TH	EC
T1	1.2	1.3	107.8	47.1	45.5	0.7	107.0	60.0	195.0
T2	1.9	0.5	96.2	28.7	56.7	1.2	211.0	64.0	384.0
T3	1.4	1.1	120.6	41.6	53.4	1.0	89.7	44.0	163.0
T4	1.1	1.0	105.9	36.7	45.5	0.7	107.0	60.0	195.0
T5	1.1	0.3	151.9	44.8	66.3	1.5	39.1	14.0	71.0
T6	1.0	1.1	102.2	31.4	40.7	0.6	108.0	70.0	197.0
T7	1.0	1.2	93.2	51.6	39.6	0.6	136.0	78.0	248.0
T8	1.1	0.3	133.7	60.0	57.9	1.2	42.4	20.0	77.0
T9	0.8	1.5	84.1	47.3	33.0	0.4	140.0	102.0	254.0
T10	1.2	0.9	89.7	41.5	43.8	0.7	147.0	82.0	267.0
T11	1.1	1.2	116.3	46.2	48.8	0.8	92.9	90.0	169.0
T12	0.6	-0.1	71.3	45.2	32.2	0.4	119.0	82.0	217.0
T13	1.7	0.7	136.6	50.0	65.5	1.7	65.5	24.0	119.0
AN14	0.3	-0.9	37.4	44.4	27.2	0.1	197.0	154.0	358.0
AN15	0.1	-1.0	3.7	44.8	7.2	0.0	236.0	50.0	494.0
AN16	0.2	-1.5	10.1	25.9	14.6	0.1	241.0	76.0	505.0
AN17	0.2	-1.4	10.4	16.3	14.0	0.1	237.0	72.0	496.0
AN18	0.0	-1.2	0.0	18.9	0.0	0.0	165.0	74.0	374.0
AN19	0.0	-0.9	0.0	15.6	0.0	0.0	125.0	54.0	314.0
AS20	0.1	-0.5	12.1	84.3	2.2	0.0	122.0	12.0	257.0
AS21	0.3	0.0	62.6	7.4	14.1	0.1	220.0	134.0	462.0
AS22	0.4	0.3	85.3	19.3	22.5	0.2	180.0	72.0	380.0
AS23	0.4	0.3	87.7	13.4	21.2	0.2	161.0	74.0	339.0
AS24	1.6	-0.8	66.1	28.4	44.9	0.8	294.0	112.0	615.0
AS25	2.4	-0.2	77.4	33.3	79.5	3.4	67.1	12.0	122.0
AS26	1.9	0.4	138.9	35.1	71.5	2.2	81.9	18.0	149.0
AS27	1.3	2.7	65.3	69.9	33.2	0.5	284.0	198.0	517.0
AS28	0.7	-0.4	69.3	20.5	32.9	0.4	119.0	82.0	216.0
AS29	1.5	0.4	150.0	25.0	68.3	1.8	47.1	16.0	85.7
AS30	1.1	0.3	156.0	44.8	66.7	1.5	49.9	14.0	90.3
AS31	1.5	1.2	137.5	35.3	60.7	1.3	90.8	34.0	165.0
AS32	3.0	0.1	114.3	41.2	80.6	3.7	208.0	80.0	378.0
AS33	0.5	0.1	50.9	12.4	15.9	0.2	322.0	242.0	585.0
AS34	1.6	0.0	70.4	63.8	47.9	0.9	189.0	88.0	344.0
AS35	1.0	1.1	60.4	28.3	27.3	0.3	256.0	220.0	466.0
AS36	1.2	0.8	101.1	43.8	46.0	0.7	96.8	60.0	176.0
AS37	0.9	0.9	104.2	40.0	41.2	0.6	97.4	60.0	177.0
AS38	0.6	-0.2	54.9	37.2	21.5	0.2	181.0	140.0	329.0
AS39	1.1	1.0	116.6	47.8	50.0	0.8	93.5	46.0	170.0
AS40	trace	trace	trace	trace	trace	trace	106.0	42.0	193.0