UNIVERSITY OF GHANA

INVESTIGATING ANTHROPOGENIC IMPACT ON GROUNDWATER QUALITY IN THE GA EAST MUNICIPALITY

BY

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DECLARATION

I do hereby declare that, with the exception of references made by other author's works, which have been duly cited, this present research work was carried out by me under the supervision of Dr. Patrick Asamoah Sakyi and Dr. Larry-Pax Chegbele. This work has not been submitted either wholly or partially anywhere for the award of a degree.

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DEDICATION

I wish to dedicate this piece of hard work to my parents Mr. Peter Yaw Bani and Margaret Bani, to my dearest Florence Bani and to all my siblings namely Theresa, Alice, Selina, Agnes, Mavis, Esther, Isaac, and Sedem.

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"Not to us, O Jehovah, not to us, but to your name give glory because of your loyal love and your faithfulness." Psalms 115: 1.

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ABSTRACT

Population growth and industrialisation have put a lot of pressure on water resources the world over. Accra is overpopulated due to influx of people from other part of the country to seek greener pastures with limited access to water supply from the Ghana Water Company Limited (GWCL) resulting in individuals supplying their own water through drilling of individual boreholes. Hydrochemical data from 39 water samples (i.e. boreholes, hand dug wells and surface water) from six communities within the Ga East Municipal Assembly were sampled and analysed for various physico-chemical water quality parameters including trace or heavy element and microbiological quality parameters using appropriate certified and acceptable international procedures in order to assess the sources and contamination of water types as well as their suitability of groundwater within the study area for drinking and irrigation purposes. Generally, groundwater in the study area is slightly acidic and slightly alkaline but majority of samples are within the World Health Organisation guideline for domestic use with samples dominated by Na ions over all other cations. From the Principal component analysis (PCA) model, it is clear that PC 1 represented rock/mineral weathering, PC2 represents contamination from agricultural waste and PC3 represents effluent from dumpsites. A Gibbbs diagram supporting the PCA also revealed that rock weathering and evaporation were the major hydrogeochemical process regulating the water chemistry of the study area. From the Piper plot, 3 facies of groundwater were obtained namely Na-Cl, Na-HCO_3^- and HCO_3-Cl. Microbial analysis revealed that almost all samples analysed were bacteriologically contaminated since Total Counts and E.Coli bacteria were high this suggested that contamination was from faecal matter as a result from human activity. The study revealed that in all three types of water sampled, surface water registered the highest Coliform Counts followed by hand dug wells and lastly boreholes. From the Human Health Risk Analysis, 35% of borehole samples pose health risk to users since their Hazard Quotient and Hazard Index were higher than 1 especially for Pb, Cd and Mn in some sampling sites. The study also revealed that children mostly stand a high risk of health problems associated with consumption of theses heavy metals in the water samples. The research showed that human activities that might be compromising the groundwater quality in the Municipality were improper disposal of waste, drilling boreholes near crack septic tanks as a results of limited space, effluents from soak aways, runoff from irrigation sites, car washing bays, auto-mechanic shops, humans and animals waste in the various communities as a result of open defaecation etc. with poor sanitation been the highest culprit.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 BACKGROUND

Groundwater is liable to contamination through anthropogenic and other sources like use of chemical pesticides, addition of industrial waste, domestic and agricultural waste to the water bodies and groundwater (Deshmukh, 2013). During last decades, it has been observed that groundwater gets polluted drastically because of increased human activities (Deshmukh, 2013). The composition of groundwater has also been affected by human activities through changes in land use and intervention in natural flow patterns (Ullah, 2009).

The quality of water also depends on agricultural land use pattern. Due to increase in population, use of chemical fertilizers, pesticides, industrialization and many other anthropogenic factors make water from various sources become polluted to a larger extent day by day (Sahu et al., 2008). Animal and human excrement are also a dangerous cause for water pollution in the under developed countries. Consumption of polluted water directly from the sources may cause water borne diseases like diarrhoea, dysentery, typhoid and paratyphoid fever, hepatitis, liver and intestinal infection, skin rash etc. (Deshmukh, 2013). Chemical contamination of drinking water may not cause immediate health problem but may have a long term effect on human health (Schot and Vander, 1992). Several researchers have carried out extensive work on the quality of groundwater from various anthropogenic activities (Brane, 1999).

Human well-being and ecosystem health in many places are being seriously affected by changes in the global water cycle, caused largely by human pressures (Arthurton et al., 2007).

The quantity and quality of surface and groundwater resources, and life supporting ecosystem services are being jeopardized by the impacts of population growth, rural to urban migration, and rising wealth and resource consumption, as well as by climate change (Arthurton et al., 2007). If present trends of impacts of population growth, rural to urban migration, and rising wealth and resource consumption, as well as by climate change continue, 1.8 billion people will be living in countries or regions with absolute water scarcity by 2025, and two thirds of the world population could be subjected to water stress (Arthurton et al., 2007). Groundwater quality could be influenced by many factors including climate, topography, aquifer lithology, surface water recharge, saline water intrusion, human activities etc. (Wu et al., 2005). Either naturally occurring processes or human activities may have a significant impact on the quality of subsurface waters and further limit its use as water supply (Huang et al., 2008).

Scientists are becoming increasingly concerned about the potential public health impact of environmental contaminants originating from industrial, agricultural, medical and common household practices, i.e., cosmetics, detergents and toiletries (Reynolds, 2003). A variety of pharmaceuticals including painkillers, tranquilizers, anti-depressants, antibiotics, birth control pills, estrogen replacement therapies, chemotherapy agents, anti-seizure medications, etc., are finding their way into the environment via human and animal excreta from disposal site into the sewage system and from landfill leachate that may impact groundwater supplies (Reynolds, 2003).

Agricultural practices are a major source and 40 percent of antibiotics manufactured are fed to livestock as growth enhancers. Manure, containing traces of pharmaceuticals, is often spread on land as fertilizer from which it can leach into local streams and rivers (Reynolds, 2003). Reynolds further notes that conventional wastewater treatment is not effective in eliminating the majority of pharmaceutical compounds. Since various contaminants do not always have coincident pollution patterns, single indicators for all contaminants are not effective. Reynolds (2003) suggests that ‘pharmaceutical contamination in the environment will involve both advanced waste and water treatment technologies and source control at the point of entry into the environment all of which are issues of on-going scientific research’.

1.2 PROBLEM STATEMENT

Population growth in Accra has led to limited supply of potable water supply provided by the Ghana Water Company Limited. Only few suburbs have access to this pipe-borne water (GOG, 2007). Some do not even have service lines in their area, especially, the peri-urban communities. This has resulted in individuals drilling boreholes to gain access to potable water. Those who cannot afford the cost of drilling boreholes tend to buy water from those who have it. People now build on small pieces of land and mostly there is not much space left to accommodate both a borehole and a septic tank (Amfo-Otu et al., 2012). The siting of these boreholes close to septic tanks can cause contamination of the water. This is because seeping of septic tank effluent into the ground water may cause diseases such as cholera, diarrhoea, typhoid etc. when the water is used for drinking purposes (Anim et al., 2010).

In developing countries, the incidence of diarrhoea diseases attributed to water consumption varies substantially between communities because of varying water quality and other behavioural and socio-economic factors (Esrey et al., 1991). It is estimated that one third of the world's population use groundwater for drinking. Therefore, water quality issues and its management options need to be given greater attention in the developing countries. Water quality is influenced by natural and anthropogenic effects including local climate, geology and irrigation practices (Deshpande et al., 2012).

In the last two decades, the rapid growth of industrialization and urbanization has created negative impact on the environment due to industrial, Municipal and agricultural waste containing pesticides, insecticides, fertilizer residues and heavy metals with water, groundwater has been polluted by leaching process (Bharati, 2012). These pollutants are being added to the groundwater and soil system through various human activities and rapid growth of industrialization which affect the human health directly or indirectly. In Ghana, groundwater resources are under increasing pressure in response to threats of rapid population growth, coupled with the establishment of human settlements lacking proper water supply and sanitation services (Anim et al., 2011).

Wide range of human induced factors causing changes in the groundwater quality of the study area is not known. Some studies (e. g., Ackah et al., 2011; Amfo-Otu et al., 2012) were reported regarding the ground water and soil characteristics in the study area. As the population of the study area is widely dispersed and the majority of people are localized, they suffer from lack of awareness regarding the quality of groundwater, which exposes the variety of health related problems in the area. In view of this, hence the need to carry out this research work in the Ga-East Municipal Assembly on the anthropogenic impacts and the human health risk assessment on groundwater quality.

1.3 RESEARCH OBJECTIVES

The main objective of this research is to establish a clear understanding of the various anthropogenic activities with impacts on groundwater quality and the human health risk associated with taking such waters in the study area. Having established the anthropogenic activities, the study also aims at determining whether the various anthropogenic activities enumerated are the sources of pollution of groundwater in the study area. In addition, the study will evaluate or assess the microbiological quality of the groundwater. It is also to determine the concentrations of the physico-chemical parameters including trace elements of the groundwater in the study area.

1.4 JUSTIFICATION

The success of this research will provide the necessary tools for all stakeholders in the water industry, to properly monitor groundwater resources for sustainable water development and management for present generation and generation yet unborn. The results of the study will serve as baseline information on groundwater quality in terms of some selected physico-chemical parameters including trace elements and microbiological parameters. In addition, knowledge from the study, would serve as a source of information on the human health risk it pose to the consumers of such waters.

1.5 STUDY AREA

1.5.1 Location and Accessibility

The area under study is the Ga-East Municipal Assembly (GEMA) in the Greater Accra Region of Ghana with its capital town as Abokobi. It lies between longitude 0 ^{0}15’ W and 0 ^{0} 21’W and latitudes 5 ^{0}35’ N and 5 ^{0}45’ N and covers a land area of approximately 166 km2.

It is one of the ten districts in the Greater Accra Region. It is boarded on the west by the Ga West Municipal Assembly (GWMA), on the east by the Adenta Municipal Assembly (AdMA), the south by Accra Metropolitan Assembly (AMA) and on the north by the Akwapim South District Assembly. Out of the total land size of about 166 km^2, about 58 km^2 of the total land size is urbanized whilst 108 km^2 is for agricultural production. It is divided into four zones with sixteen operational areas consisting of forty-two communities (GEMR, 2006).

Geomorphologically, the study area forms part of the Accra plains, is generally flat and undulating (Dickson and Benneh, 1980). Thus, the nature of drainage pattern has called for most households within GEMA to depend on hand dug wells and boreholes for their water supply. The study area forms part of the dry equatorial climatic conditions and is characterized by two rainfall maxima. The major rainy season occurs between May and July with the peak occurring in June while the minor one occurs between September and October with the peak occurring in October. Generally the rainfall in the study area is low with mean annual value being approximately 900 mm. The mean temperature is 26 ^{0}C. The vegetation is mainly coastal grassland and shrub (Dickson and Benneh, 1980).

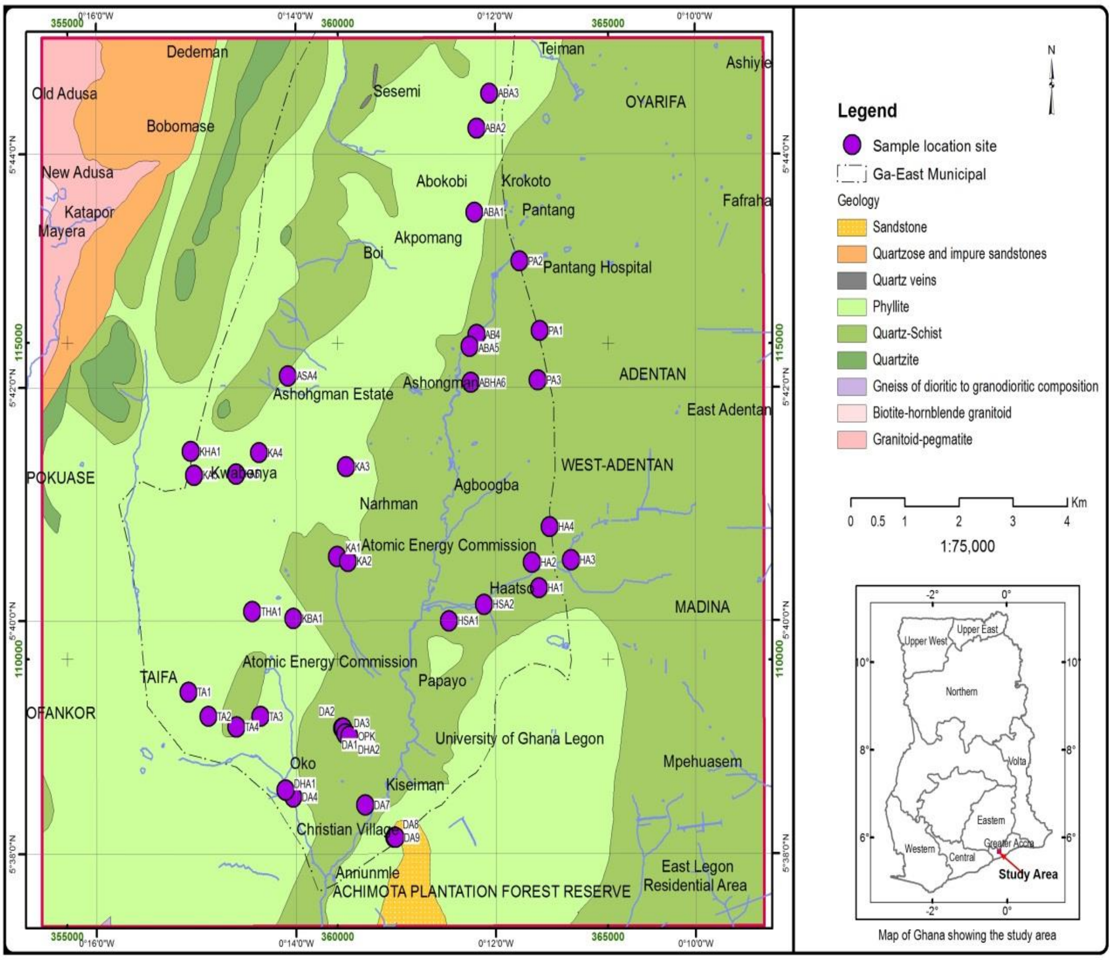

Figure 0-1: Sample location map of the study area.

1.5.2 Population and Size

The 2010 National Population and Housing Census put the Municipality's population at 259,668 with male and female population of 127,258 and 132,410 respectively with an average household size of 6.2 (GSS, 2010). This indicates a great pressure of population on land and water resources. Potable water supply in the peri-urban areas of the Municipality has been a major challenge to the assembly. There are about 65 settlements in the Municipality with varying populations and Abokobi is the capital. The population is concentrated mainly along the urban and peri-urban areas of the Municipality particularly along the border with

AMA to the south. Some of these communities are Dome, Taifa, Haatso, and Kwabenya just to mention a few.

1.5.3 Geology

The greater part of the study area is underlain by Dahomeyan formation. It comprises alternating bands of massive acidic and basic gneisses, schist and migmatite (Quist, 1976). The other geological units include the Togo series, the tertiary and recent sediments. The Togo series occurs mainly on the north-western part of the study area and mainly consist of quartzites and phyllites. Other rock types include shale, sandstone, schist, and silicified limestone. The Accraian series consists of sandstone, grits, and shales found in the vicinity of the city. Since the main rocks are inherently impermeable, groundwater in the study area is controlled by the development of secondary porosities such as fractures, faults, and associated weathered zones. The depth of weathering is highly variable and it is greater along the foothill of the Akwapim-Togo ranges where it reaches 47 m but least in the heart of the city, where it rarely exceeds 6 m. The weathered zone aquifer and the fractured zone aquifer are the main aquifers in the study area and their yields are highly variable (0.7 m^3h^{-1} to 27.5 m^3h^{-1}) with a mean of 2.7 m^3h^{-1} (WRI, 1993).

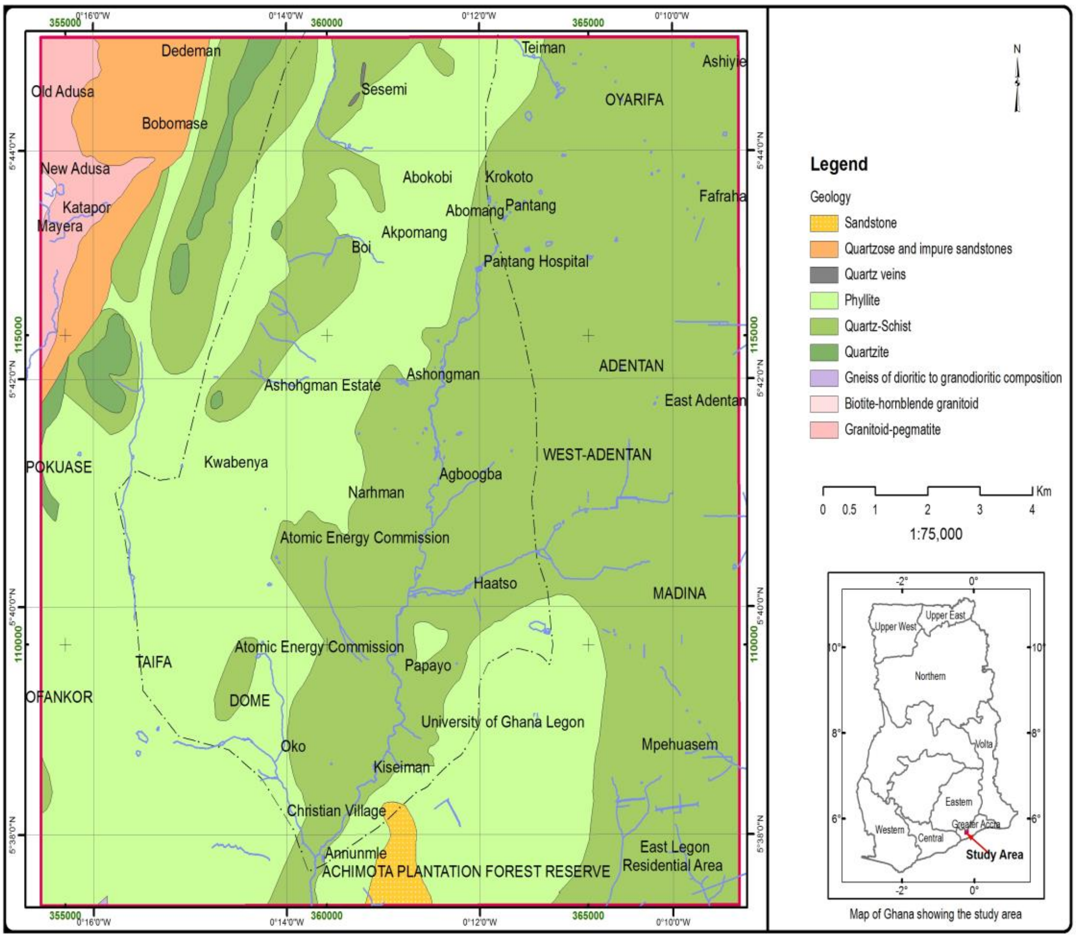

Figure 0-2: Geological map of the Study Area

1.5.4 Hydrogeology

Rocks underlain in the study area are of considerable importance in the water economy of Ghana as they underlie extensive and usually well populated areas. They are not inherently permeable, but secondary permeability and porosity have developed as a result of fracturing and weathering (Dapaah-Siakwan and Gyau-Boakye, 2000). The yields of boreholes associated with the weathered zones depend on the amount of rainfall. Where the amount of rainfall is less and the depth of weathering is thin and there are no fractures, the groundwater potential is very low or non-existent. The terrain is generally flat and undulating with few isolated inselberg that seldom rise to 70 m above sea level.

1.5.5 Climate and Vegetation

The climate is typically characterized by prevailing high temperatures with distinct variations in the duration, intensity, and seasonality of rainfall. The dry equatorial climate of the south-eastern coastal plains and the wet semi-equatorial climate are the two distinct climatic zones having two yearly rainfall patterns (Dapaah-Siakwan and Gyau-Boakye, 2000).

The study area falls in the savannah agro-ecological zone with rainfall pattern being bi-modal. The average annual temperature ranges between 25.1 ^{O}C in August and 33 ^{O}C in February and March which are also normally the hottest . The Municipality has two main vegetation namely shrub lands and grassland. The shrub lands occur mostly in the western outskirts and in the north towards the Aburi hills and consist of dense cluster of small trees and shrubs that grow to an average height of about five meters (Dapaah-Siakwan and Gyau-Boakye, 2000). The grassland around the southern parts of the district has now been encroached upon by human activities including settlements (GEMR, 2006).

1.5.6 Relief and Drainage

The Districts land area consists of gentle slopes interspersed with plains in the west. The Akwapim range rises steeply above the western end and lies generally at 375 m to 420 m north of Aburi and fall to 300 m southward (Dapaah-Siakwan and Gyau-Boakye, 2000). There are a few rivers and seasonal streams most of which are threatened by human activities. This includes the Sisami stream at Sesemi and the Dakubi at Ajako. Other small ponds exist at Abloradjei, Sesemi, Danfa, Otinibi and Old Ashongman. Most of these ponds are also threatened by human activities (GEMR, 2006).

1.5.7 Water Supply and Sanitation System

Potable water supply in the urban/peri-urban areas of the study has been a major challenge in the Municipality, especially when the assembly has no direct control over urban water supply. Areas like Dome, Taifa, Agbogba, Musuko etc. have limited or no access to pipe-borne water. Others depend on tanker services and a few hand dug wells (Ackah et al., 2010). In addition, a number of people have access to some type of sanitation facilities either public or private. Others also resort to indiscriminate defecation in gutters, school compound and public refuse dumps. Total sanitation coverage is estimated at 31 % for household facilities and 29 % for institutions. Pit latrine even though not approved by the assembly is being used by some households even in the urban communities (Amfo-Otu et. al., 2012).

Moreover, the rate of waste generation and management in the Municipality is a matter of concern to the all and sundry. With the increasing influx of people and the rapid urbanization, huge amounts of human and industrial waste are generated at an alarming rate. It is estimated that about 750 tonnes of solid waste is generated monthly out of which 490 tonnes are collected which represents 63%. This leaves a substantial amount of backlog that creates various kinds of inconveniences including health hazard to people in the Municipality.

CHAPTER TWO

LITERATURE REVIEW

2.1 GROUNDWATER HYDROCHEMISTRY

Groundwater quality is one of the most important aspects in water resource studies (Ackah et al., 2011). The quality of groundwater extracted is the resultant of all the processes and reactions that act on the water from the moment it condenses in the atmosphere to the time it is discharged by the well (Arumugam and Elangovan, 2009). It therefore means that even though groundwater is a common resource, the chemical properties of the water would determine its suitability for use (Ackah et al., 2011).

Yidana et al. (2007) noted that the efficient development and management of groundwater requires a good understanding of the hydrochemical properties of the rock that form the aquifers in these areas through the understanding of the transmissive properties of aquifers to facilitate ground water exploration. Groundwater hydrochemistry is also a product of both natural and anthropogenic factors. Excluding the anthropogenic impacts, the chemical composition of surface and groundwater is controlled by many factors that include the mineralogy of watershed and aquifers composition and precipitation, climate and topography (Yidana et al., 2007). These factors combined variously to create water types which change spatially and or temporally (Yidana et al., 2007). The chemical composition of water also changes as it moves through the aquifer and changes as a result of dissolution, precipitation, ion exchange, concentration and other chemical reactions (Schoeller, 1997).

Groundwater hydrochemical studies in parts of the Northern Region of Ghana indicate that the major ion concentrations are within the respective WHO maximum acceptable limits for drinking water. This study further found that although nitrate concentrations in some boreholes were high, groundwater in the study area was chemically potable and suitable for domestic and agricultural purposes (Anku, 2007). There are however a number of key exceptions such as pertains in Bongo area (Apambire et al., 1997), where the natural weathering of fluorite elevate fluoride beyond tolerable limits for consumption.

Ajayi (1998) characterized groundwater facilities in coastal Nigeria and concluded that they were generally of poor quality and incomplete with respect to total ionic constituents. He further concluded that groundwater from the three artesian boreholes at Agbabu were brackish and the available data do not permit the origin of the groundwater to be proved conclusively that the water will be suitable for most industrial uses without further treatment. Again, Singh and Singh (2008) characterized the quality of water in Gwalior region in India using Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) and concluded that the groundwater is considered to be suitable for irrigation purpose. However, a few parameters fall at higher side of the WHO (2004) limit and thus minimizing its suitability for drinking purposes without treatment. Johnson and Zhang (2010) classified water suitable for irrigation in Oklahoma using a plot of percent sodium plotted against electrical conductivity (EC).

The major cations include sodium , potassium, calcium and magnesium and the major anions includes chloride, sulphate, fluoride and nitrate. The availability and concentration levels of these ions in water determine the potability and suitability of water for domestic and agricultural purposes. According to Aliou (2010), Water Quality Index (WQI) is one of the numerous methods used to characterize the suitability of water for domestic purposes using some chemical and physical components which affect the human body when the recommended daily intake is exceeded. Standard hazard weights are assigned to the chemical parameters according to their toxicity and a relative weight computed (Ahialey et al., 2010). The standard weight and the computed relative weight will then be used along with the WHO standard for the respective parameter to compute the WQI. Sodium content is very crucial in determining the suitability of water for irrigation purposes. Sodium enrichment in soils brings about permeability problems; the Na^+ in the water tend to replace Ca^{2+} and Mg^{2+} ions in the soil leading to clay expansions and eventually minimizing air and water circulation (Ahialey et al., 2010).

Furthermore, water resources and aquifer characterizations in Ghana have been carried out in the Keta basin by Yidana et al. (2010). Most geochemical characterizations were done using the conventional graphical representations especially the piper trilinear diagram. Examples include the works of Kuma (2004), Tay et al. (2008) and Ahialey et al. (2010). Water with computed RSC values greater than 2.5 meq/L is not suitable for irrigation while values less than 1.25 meq/L are good. The intermediate concentrations are doubtful hence can or cannot be used. In addition to the above methods of identifying suitable irrigable water, the Permeability Index (PI) can also be calculated. PI is a measure of the total sodium and another determinant of water quality is the alkalinity of the water. Alkalinity is the measure of the total acid neutralizing capacity of the water and acidity is the base-neutralizing capacity of the water. Alkalinity is expressed in terms of bicarbonate and carbonate and acidity of water generally is expressed in terms of hydrogen ion (Walton, 1970). The extent to which water is alkaline or acid determines the quality and the purpose for which it could be used.

2.2 GROUNDWATER ANALYTICAL TECHNIQUES

2.2.1 Multivariate Statistical Analysis

The application of multivariate statistical methods to multivariate geo-environmental datasets have facilitated the unveiling of hidden structures in datasets and assisted in resolving key geo-environmental problems at various scales (Yidana, 2010). Although statistical associations do not establish cause-and-effect relationships, they provide helpful associations from which such relationships can be deduced (Yidana, 2010).The application of these advanced statistical models in recent times in the geosciences has been diverse and ranges from the resolution of simple geo-environmental problems to the determination of groundwater flow directions (Farnham et al., 2003; Stetzenbach et al., 2001), the identification of factors that influence dam hydrologic changes (Matteau et al., 2009), and the characterization of hydrochemical variations among groundwater basins (Yidana, 2010). Other classical applications of multivariate statistical methods in the Earth Sciences are contained in Güler et al. (2002), Cloutier et al. (2008), Jiang et al. (2009), Kim et al. (2009), and Yidana et al. (2010).

Multivariate statistical analyses such as principal component analysis (PCA) and cluster analysis (CA) provide a reliable alternative approach for understanding and interpreting the complex system of water quality with the capability of analysing large amounts of data (Akbal, 2011) and distinguishing complex relationships among many variables (Glynn, 2005). As such, multivariate statistical analysis has been used by many researchers all over the world to analyse water quality. For example, Singh et al. (2012) analysed the suitability of groundwater in Imphal for drinking, domestic and agricultural activities using CA, PCA, and factor analysis (FA). Tlili-Zrelli et al. (2012) used multivariate statistical analyses, combining PCA and hierarchical cluster analysis (HCA) to investigate natural and anthropogenic processes controlling the groundwater mineralization and quality. Multivariate statistical analysis was also used by Akbal et al. (2011) to study water and sediment quality on the mid-black sea. By applying PCA, they were able to extract five and three factors that were responsible for 87.63% and 84.73% of the total variations in surface water and sediments, respectively. Shyu et al. (2011) integrated factor analysis with kriging and information entropy theory to determine the stability of groundwater quality variation.

Multivariate statistical techniques have also been employed to identify the different sources of solutes in groundwater ; dissolution of calcium and magnesium carbonate minerals, weathering of acid volcanic minerals, alteration of manganese containing alkaline silicates, leaching of halite deposits of meteoric origin, contamination from agricultural and urban wastewaters, evaporative effects due to intensive irrigation (Mahlknecht et al., 2004). Cloutier et al. (2008) used principal component analysis with hierarchical cluster analysis to delineate confined and unconfined aquifer systems. They were able to distinguish seven groundwater associations on the basis of the lithology. From the results of the Q-mode HCA, Cloutier et al. (2008) defined confinement indices which indicated the level of confinement of the aquifers in the area.

In their bid to discover the hidden processes responsible for high nitrate concentrations in groundwater, Jiang et al. (2009) applied multivariate methods to the major physico-chemical parameters of groundwater and ascribed anthropogenic contributions to groundwater contamination in the area. They combined factor analysis with geospatial methods to determine the spatial distribution of the major causes of variation in groundwater quality in the area. Also, Yidana et al. (2010) used a similar methodology to study sources of variation, and the spatial distribution of groundwater salinity in the Keta basin in Ghana. In addition to the factor model and ordinary kriging of the resulting factor scores, Yidana et al. (2010) used Q-mode HCA to classify groundwater from the unconfined aquifer units, into useful hydrochemical facies. The outcome of the study of Yidana et al. (2010) provided another angle to the assessment of groundwater quality variations in the Keta basin. Earlier, Helstrup et al. (2007) used principal component analysis and Q-mode HCA to classify groundwater from wells of various depths in the Keta basin and some parts of the Republic of Togo.

Factor and cluster analysis are the most copiously used multivariate statistical methods in geo-environmental studies. Their combined use facilitates an understanding of complex geo-environmental problems, and when used with an expert understanding of the underlying issues, they provide helpful links for the resolution of such geo-environmental problems (Yidana et al., 2010). Factor analysis is a data reduction tool which reduces a large set of data of many variables into a smaller number of uncorrelated factors which provide clues on trends in the data (Kaiser, 1960). Various rotation methods are usually used to optimize the results of the factor analysis. Varimax rotation (Kaiser, 1960) is the most frequently used rotation method in the literature. It is the application of an orthogonal matrix to the results of factor analysis with an objective of maximizing the differences among the resulting factors in the final factor model (Kaiser, 1960). In water quality studies, factor analysis is used in a similar way as Piper (1944) trilinear diagrams, with an added advantage that the researcher is able to include other parameters which are not usually used in conventional graphical treatment of hydrochemical data such as the Piper (1944) diagrams.

However, cluster analysis places variables or samples into associations based on their similarities and/or dissimilarities with each other in the field. Similar variables or samples are connected to each other in the same cluster (group) whilst dissimilar variables are grouped into different clusters (groups). The dendrogram is the visual result of cluster analysis and shows spatial associations of parameters or cases. Different clustering methods exist but the most frequently used is the hierarchical cluster analysis (HCA) (e.g. Cloutier et al., 2008; Banoeng-Yakubo et al., 2009; Yidana, 2010).

2.2.2 Graphical Evaluation of Water Quality

Another statistical technique used in groundwater hydrochemical interpretation is graphical displays. Graphical displays like piper diagrams, stiff patterns and diagrams, flow path observation or molar relationships are also essential (Yidana et al., 2007) in interpreting groundwater hydrochemical data. Graphical methods form one of the conventional approaches used in presenting chemical data of major ions that typifies groundwater. Hem (1985) says graphing of water analysis is a technique and not an end in itself. Major ions such as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and sulphate (SO_4^{2-}) are graphed in various relationships and conclusions arrived at (Hem, 1985).

These techniques are used to identify water samples with similar chemical composition and then grouped since samples with these similar characteristics often bear similar hydrologic background, originate from similar recharge areas, and have the same infiltration pathways and flow paths in terms of climate and residence time (Güler et al., 2002). The common methods include bar charts (Collins bar graph), pie charts, histograms and Schoeller semi-logarithmic graphs. The Schoeller semi-logarithmic diagrammatically presents the concentration of major ions of all the samples analysed on a single semi- log sheet with the ions on the normal side and the concentration on the logarithmic side. The resulting plot is then visually analysed for patterns and deductions.

Stiff (1951) came up with a graphical method of reducing chemical data to obtain a pattern. This consisted of series of scaled (units in milliequivalent per litre or meq/L) vertical lines along a centralized horizontal line. Values of major cations are plotted to the left of the horizontal lines while the major anions are plotted on the right side. By convention, the first vertical axis represents (Na^+) and (K^+) for cations and (Cl^-) for anions. (Ca^{2+}) and (HCO_3^-) are plotted on the second vertical axis. The third vertical axis is occupied by (Mg^{2+}) and (SO_4^{2-}). A fourth axis could be used to represent ions that are of interest in a particular investigation. The plotted points are joined to obtain polygons whose spread indicates the most abundant ions in the water analyzed. Though the method is able to establish patterns, it is constrained by its inability to handle large volumes of data (Yidana et al., 2010). To offset such a weakness, Yidana et al. (2010) showed that the stiff diagrams could be generated for water types after they have been clustered (spatial water associations). The Gibbs (1970) diagram plots the total dissolved solids (TDS) on a logarithmic axis against the ratio of sodium and the sum of sodium and calcium on a linear axis. It is used to explain some of the mechanisms that control the chemical composition of inland waters.

2.2.3 Geographic Information Systems (GIS) and Water Quality

Remote sensing and GIS technologies have been recently used by many researchers as very useful tools in the field of hydrogeology. Geographic Information System (GIS) is a powerful tool and has great promise for use in environmental problem solving. Most environmental problems have an obvious spatial dimension and spatially distributed models can interact with GIS (Goodchild et al, 1993). Ashraf et al., (2011) applied GIS for the determination of groundwater quality suitable for crops influenced by irrigation. Features considered in this study for evaluation were the salinity, water infiltration rate, and specific ion toxicity. The SAR, ions Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-}, Cl^{-}, EC, TDS and pH were analyzed as the evaluation indexes. The EC map indicated the presence of about 0.04 % of the study area; groundwater lie in good range (none degree of restriction on use) 61.38 % slight to moderate and 38.58% severe for irrigation purposes. The suitable zones for ECW were in the central and northwestern and portion of south of the study area (61.32 %). The quality of groundwater for the sodium hazard on infiltration was 98.9% of study area none degree of restriction on use in 0.6 % slight to moderate and 0.5 % severe.

Yidana and Yidana (2010), in the study of the southern part of the Voltaian sedimentary formation used GIS with other methods to study the controls on the hydrochemistry and the severity of the controlling factors at different locations in the flow system. The study revealed three main factors controlling the hydrochemistry of the area, namely; silicate mineral weathering, carbonate mineral weathering and reverse cation exchange.

2.3 GROUNDWATER OCCURRENCE

The occurrence of groundwater within the earth's crust and the emergence of springs at the ground surface are determined by the lithology of geological materials, regional geological structure, geomorphology of landforms and the availability of recharge sources (Hiscock, 2005). Movement of groundwater through the saturated zone occurs in response to two forces; gravity to pull water downwards and pressure to cause water to move upwards (Page, 1987).

Groundwater resource becomes contaminated when its natural constituent is altered; posing a reasonable risk in its use or making it unusable for the purpose it serves. The alteration is a result of pollutants which are transported from the land surface from either a point or a diffuse source through the unsaturated zone to the water table (Hiscock, 2005). They may affect both aquifers in the saturated and unsaturated zone if conditions are favourable. Depending on the nature of the pollutant, some dissolve completely in water to form solution whilst others do not, it is common practice to track chemical movement by studying movement of chemicals in the vadose zone (Hiscock, 2005).

However, some soils and rocks have natural defence mechanism in the subsurface environment to mitigate the effects of pollutant sources by reducing its concentration as it travels through the soil profile. Page (1987) names the processes to include the physical process of dilution of pollutants by recharge water, chemical process such as adsorption, decay and hydrolysis, and biological processes. These can permanently remove or alter chemical compounds that are contained in the contaminants. Worldwide, more than 2 billion people depend on groundwater for their daily supply (Kemper, 2004).

In Ghana like other parts of the world, groundwater occurrence depends on the following parameters (Dapaah-Siakwan et al., 2004): rock type and geological structures-fractures and weathering, porosity and permeability, degree of pore interconnection and climate. The occurrence of groundwater in Ghana is associated with three main geological formations which are: basement complex, comprising crystalline igneous and metamorphic rocks, consolidated sedimentary formations underlying the Volta basin, and Mesozoic and Cenozoic sedimentary rocks (Dapaah-Siakwan et al., 2004).

The majority of the water bearing zones occurs in the crystalline rocks as a result of secondary permeability developed through faults, fracture joints and weathered zones (e.g. granite, phyllite and quartzite). The depths of aquifers are normally between 10 m and 60 m and yields rarely exceed 6 m^3/hr (Dapaah-Siakwan et al., 2004). In the Mesozoic and Cenozoic formations occurring in the extreme south eastern and western parts of the country, the aquifer depths vary from 6m to 120 m. There are also limestone aquifers, some of which are 120 m to 300 m in depth with average yield of about 184 m^3/hr (Dapaah-Siakwan et al., 2004).

2.4 GROUNDWATER QUALITY

Groundwater is actually a complex, generally dilute, chemical solution. The chemical composition is derived mainly from the dissolution of minerals in the soil and rocks with which it is or has been in contact. The type and extent of chemical contamination of the groundwater is largely dependent on the geochemistry of the soil through which the water flows prior to reaching the aquifers (Zuane, 1990). The chemical alteration of the groundwater depends on several factors, such as interaction with solid phases, residence time of groundwater, seepage of polluted runoff water, mixing of groundwater with pockets of saline water and anthropogenic impacts (Stallord and Edmond, 1983; Dethier, 1988; Faure, 1998; Umar and Absar 2003; Umar et al., 2006).

Groundwater in its natural state is generally of good quality. This is because rocks and their derivatives such as soils act as filters. However, not all soils are equally effective in this respect and therefore pathogens contained in human excreta such as bacteria and viruses are likely to be small enough to be transmitted through the soil and aquifer matrix to groundwater bodies (Lewis et al., 1982). Rainfall is a dilute chemical solution and contributes significant proportions to some constituents in groundwater, especially in regions with little soil cover where hard compact rocks occur at or near the surface. As water flows through the ground the dissolution of minerals continues and the concentration of dissolved constituents tends to increase with the length of the flow path. At great depths, where the rate of flow is extremely slow, groundwater is saline, with concentrations ranging up to ten times the salinity of the sea. Groundwater can become not potable if it becomes polluted and is no longer safe to drink. In areas where the material above the aquifer is permeable, pollutants can seep into groundwater. This is particularly so in a fractured aquifer.

2.4.1 Physico-Chemical Indicators for Water Quality

The dissolved constituents in groundwater, including calcium, magnesium, sodium, potassium, bicarbonate, nitrite, sulphate and chloride occur in the form of electrically charged ions. Many other minor constituents of groundwater such as iron, manganese and fluoride, Zinc and Lead are trace elements which may be found in groundwater. The pH measures the acidity or alkalinity of the water while the conductivity is the ability of the groundwater to conduct an electrical current. Conductivity is a function of temperature, types of ions present and the concentrations of the ions. The total dissolved solids, (TDS) an index of conductivity, has a direct relationship to salinity and high total dissolved solids limits the suitability of water for potable use (Davis and DeWiest, 1966). Fluoride, when present in drinking water at a concentration of about 1 milligram per litre (mg/L), helps prevent dental cavities. However, exposure to high levels of fluoride, which occurs naturally, can lead to mottling of teeth and, in severe cases, crippling skeletal fluorosis (WHO, 2006).

Generally, chemicals occurring in drinking-water are of health concern only after extended exposure for years. The only exception is nitrate. Nitrate and nitrite in water has been associated with methaemoglobinaemia, especially in bottle-fed infants. With a methaemoglobin level of 3-15%, skin can turn to pale gray or blue. Nitrate may arise from the excessive application of fertilizers or from leaching of wastewater or other organic wastes into surface water and groundwater (WHO, 2006). The nitrite ion contains nitrogen in a relatively unstable oxidation state. Chemical and biological processes can further reduce nitrite to various compounds or oxidize it to nitrate (Anon, 1987). Because of its solubility and its anionic form, nitrate is very mobile in groundwater (Fytianos and Christophoridis, 2003). It tends not to adsorb or precipitate on aquifer solids (Hem, 1985).

High chloride and sodium contents may impart saline taste, which may affect its acceptability for potable purposes. High concentration of sulphate may give bitter taste and also cause laxative effect. Calcium is obtained mainly from rocks containing limestone and gypsum. Small amounts come from igneous and metamorphic rocks while potassium occurs essentially in rock-salt deposits. Wastewater from industries and agricultural practices through excessive use of potash-rich fertilizers can also increase the potassium levels in groundwater. Changes in water quality occur progressively, except for those substances that are discharged or leach intermittently to flowing surface waters or groundwater supplies, such as, contaminated landfill sites.

Hardness is a property of water that determines its ability to easily form lather with soap. Total hardness is directly related to the concentrations of calcium and magnesium. Iron and manganese in ground water originate when water gets into contact with mineral groups and the weathering product that contain iron or manganese. Their concentrations can also be affected by wastewater from chemical industries. Excessive amount of iron and manganese are objectionable for both domestic and industrial water supplies because of their tendency to stain laundry and plumbing fixtures. In areas with aggressive or acidic waters, the use of lead pipes and fittings or solder can result in elevated lead levels in drinking-water, which cause adverse neurological effects (WHO, 2006). Guideline values are derived for many chemical constituents of drinking-water. A guideline value normally represents the concentration of a constituent that does not result in any significant risk to health over a lifetime of consumption.

2.4.2 Trace Element Indicator of Water Quality

Trace elements are generally present in small concentration in natural water system. Their occurrence in groundwater and surface water can be due to natural sources such as dissolution of naturally occurring minerals containing trace elements in the soil zone or the aquifer material or to human activities such as mining, fuels, smelting of ores and improper disposal of industrial wastes (Lowe, 1970). The trace metals in water behave in a typical manner. No single mechanism is sufficient to explain the process that are undergoing in the water (Sudhira and Kumar, 2000).

Trace metals like Fe, Mn, Cu, Zn, Co, Ni etc, are very important for the proper functioning of the biological system and their deficiency or excess in the human system can lead number of disorders other trace metals like Pb, As, Hg etc. are not only biologically non-essential but definitely toxic (Sudhira and Kumar, 2000). The potential toxic metal element such as Cr, Pb, Cu, Zn etc. are identified to cause health hazards in animals. In case of many heavy metals, bio-magnification occurs through food chain so, it is necessary to discuss the theoretical aspects of trace metals for easy understanding of their metabolic activities (Sitakumar et al., 2001).

Copper and Fe is mixed in groundwater by rocks bearing iron and copper bearing ores via; cuprite, melakite, azurites, hematite, magnetite and iron pyrite. Iron in surface water is generally present in the ferric (Fe III) state (Mohapatra and Singh, 1999). Concentrations of Fe greater than 1mg/L have been reported to occur in groundwater. The average daily requirements of iron is considered to be 10 mg. Manganese plays a role in the proper functioning of flavoroteins and in the synthesis of sulphated mucopolysaccaharides, cholesterol, haemoglobin and in many other metabolic processes (Bowen, 1972). Leaching of zinc from galvanized pipes, brass and zinc containing fittings plays a serious role in groundwater pollution, but in required quantity it is very essential for human metabolism. Dye and tannery industries pollute the water through chromium and other harmful chemicals (Bowen, 1972).

2.4.3 Bacteriological Indicators for Water Quality

The greatest risk from microbes in water is associated with consumption of drinking-water that is contaminated with human and animal excreta, although other sources and routes of exposure may also be significant (Anim et al., 2010). Groundwater from a shallow origin is particularly susceptible to contamination from a combination of point and diffuses sources (Fuest et al, 1998; Nolan and Stoner, 2000). Faecal indicator bacteria, including E. coli, are important parameters for verification of microbial quality. Analysis for faecal indicator bacteria provides a sensitive, although not the most rapid, indication of pollution of drinking-water supplies.

Total coliforms are generally measured in 100-mL samples of water. A variety of relatively simple procedures are available based on the production of acid from lactose or the production of the enzyme β-galactosidase. The procedures include membrane filtration followed by incubation of the membranes on selective media at 35–37 °C and counting of colony forming units after 24 hours (WHO, 2006).

2.4.4 Quality Criteria for Irrigation Purpose

Electrical conductivity and Na^+ play a vital role in suitability of water for irrigation. Higher EC in water creates a saline soil. Harmful effects of irrigation water increases with the total salt concentration, irrespective of the ionic composition. Higher salt content in irrigation water causes an increase in soil solution osmotic pressure (Thorne and Peterson, 1954). The salts apart from affecting the growth of plants also affect the soil structure, permeability and aeration which indirectly affect plant growth. Sodium Adsorption Ratio (SAR), Ratio of Dissolved Sodium (RDS) as %Na, or Residual Sodium Carbonate (RSC) might equally be used for calculating a value which can be utilized as an index of ground water suitability for irrigation purposes (Shaki and Adeloye, 2006). Sodium Adsorption Ratio is the most commonly used for evaluating groundwater suitability for irrigation purposes (Ayers and Westcot, 1985). It is normally expressed as Na content or alkali hazard which is normally expressed in Sodium adsorption ratio (SAR) (Rao, 2005). SAR is expressed as in equation 2.1 (Hem, 1991):

$$SAR = \frac{Na}{\sqrt{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)}} \qquad (2.1)$$

where the ion concentrations are expressed in meq/L.

SAR values in irrigation waters have a close relationship with the extent to which Na is absorbed by soils. If water used for irrigation is high in Na and low in Ca, the ion exchange complex may become saturated with Na, which destroys soil structure because of dispersion of clay particles. As a result, the soil tends to become deflocculated and relatively impermeable. Such soils become very difficult to cultivate. The total concentrations of soluble salts in irrigation water can be classified as low (S1:<10), medium (S2:10-18), High (S3:18-26) and very high (S4:>26) (Rao, 2006). The zones (S1-S4) have the value of EC less than 250 µS/cm, 250 µS/cm to 750 µS/cm, 750 µS/cm to 2250 µS/cm and more than 2250 µS/cm respectively.

The US Salinity diagram (1954) is used widely for rating irrigation waters, where SAR is plotted against EC. The analytical data plot is shown in.

2.5 WATER POLLUTION

2.5.1 The Emerging Trend in Groundwater Pollution

However, groundwater is the most important source of domestic, industrial and agricultural water supply in the world. Many communities in Africa depend heavily on groundwater. Exploitation of surface waters has reduced, ensuring an increasing reliance on groundwater abstraction due to increasing pollution with the concomitant rise in the cost of water treatment (Kortatsi, 2007). In Ghana, about 70% of the total population relies heavily on groundwater for drinking purposes (Kortatsi et al., 2008). 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).

Suitability of water for various uses depends on type and concentration of dissolved minerals and groundwater has more mineral composition than surface water (Mirabasi et al., 2008). 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 change in the quality of water has far reaching consequences in terms of its effects on man and biota (Mirabasi et al., 2008). Water quality complaints have been used to monitor treatment operations and quantify the extent of distribution and water quality problems (Dietrich, 2006; McGuire, et al, 2005; Khiari et al., 2002; Burlingame and Anselme, 1995). Research has shown that rural water wells are not tested as suggested by professionals, and are contaminated with pathogens and chemical from various sources (Charrois, 2010). Others have shown that, 33% documented outbreaks of water-related infections could be attributed to groundwater systems (Reynolds, Mena and Gerba, 2008).

Groundwater is globally important for human consumption, and changes in quality with subsequent contamination can undoubtedly affect human health. It is also important for the support of habitat and for maintaining the quality of base flow to rivers. The chemical composition of groundwater is a measure of its suitability as a source of water for human consumption and for other purposes, and also influences ecosystem health and function (Appelo and Postma, 1993). Groundwater pollution has become a major subject of public concern the world over. Despite the large volume of water that covers the surface of the earth, only 1 % is inland or fresh and easily available for human use (Bockris, 1978). Only 30 % of Ghanaians have access to safe drinking water. Over 50 % of Ghanaians use “unprotected” sources of water (Ministry of Health, 1999). Rural communities in Ghana, which form about 70 % of the total population, rely heavily on groundwater as the main source of drinking water. Groundwater quality is, therefore, critical to the quality of health of the people in these areas.

Natural geochemical and biochemical, as well as anthropogenic impact on groundwater do not only threaten the quality of human health but also poses a threat to sustainable development and management of groundwater resources (Appelo and Postma, 1993). Groundwater may, thus, be prone to chemical contamination. A number of factors influence groundwater hydrochemistry. Gibbs (1970) proposed that rock weathering, atmospheric precipitation, evaporation and crystallization control the groundwater hydrochemistry. Apart from natural factors influencing water quality, human activities such as domestic and agricultural practices impact negatively on groundwater resources. Pollution of water bodies as a result of metal toxicity has become a source of concern among consumers. This concern has become alarming in response to increasing knowledge on their toxicity to human health and biological system (Anazawa et al., 2004). Unfortunately, most countries in the developing world get their drinking water supplies from underground sources. Most of the sources are contaminated with bacteria, viruses, heavy metals, nitrates, and salt. These enter into drinking water supply sources as a result of poor treatment and disposal of human and livestock waste, industrial discharges and overuse of limited water resources (Lee and Brodie, 1982).

The current trend of increasing urbanization in many countries has compounded the difficulties in disposal of liquid and solid waste, and this has led to increased occurrence of water related diseases (Palaniappan et al., 2010). Generally, areas that are replenished at a higher rate are generally more vulnerable to contamination than those replenished at a lower rate. Large fractures in bedrock also contribute to contamination by providing a pathway for the contaminants (Palaniappan et al., 2010). This has led to a large number of deaths and health problems from diarrhoea, cholera and hepatitis B, and shortages of potable drinking water. All natural waters contain many dissolved substances. Contaminants such as bacteria, viruses, heavy metals, nitrates and salts have polluted water supplies as a result of uncontrolled human activities and untreated industrial waste discharges (Singh and Moseley, 2003).

However, groundwater resources in the Ga east Municipal area is under threat from increased abstraction as a result of the population explosion, the rapid increase in the number of wells, the progress in pumping technology and the influx of borehole drilling companies and their negative activities. Another major threat is from the pollution due to inappropriate disposal of domestic waste. Runoff from agricultural farms quite often due to the poor management of hand dug wells in particular; polluted surface waters seep into them with its attendant water-borne diseases (Nkansah et al., 2010). Most studies linked the physico-chemical quality of groundwater to health. However, there seems to be a gap between groundwater quality and its effect on distribution systems and consumer complaints. Reports suggest that water quality tests are either not regularly done or not done at all for rural water supply systems, wells and boreholes as suggested by experts in the field (Amfo-Otu et al., 2012).

2.6 HUMAN RISK ASSESSMENT

Heavy metals contamination is a major problem of our environment and they are also one of the major contaminating agents of our food and water supply. This problem is receiving more and more attention all over the world in general and developing countries in particular (Abdulla and Igbal, 1991). The probability risk assessment technique has been adopted by a number of researchers (Solomon et al., 1996; Giesy et al., 1999; Cardwell et al., 1999; Hall et al., 1999, 2000; and Wang et al., 2002) to fully utilize available exposure and toxicity data. However, these methods are only applied to quantify the magnitude of health risks of carcinogenic pollutants, but not for quantifying non cancer risks.

Current non cancer risk assessment methods do not provide quantitative estimates on the probability of experiencing non cancer effects from contaminant exposures. These are typically based on the hazard quotient (HQ), which is a ratio of determined dose of a pollutant to the dose level (a Reference Dose or R_fDo). If the ratio is less than 1, there will not be any obvious risk (USEPA, 2013). Conversely, an exposed population of concern will experience health risks if the dose is equal to or greater than the R_fDo. Although the HQ-based risk assessment method does not provide a quantitative estimate on the probability of an exposed population experiencing a reverse health effect, it indeed provides an indication of the risk level due to pollutant exposure. This risk estimation method has recently been used by Chien et al. (2002) and proved to be valid and useful. This non cancer risk assessment method was also applied in this study.

2.6.1 Hazard Quotient

Hazard Quotient (HQ) for the consumers of the water was assessed by the ratio of daily intake (DI) to the oral reference dose (R_fD_o) for each metal (USEPA, 2013 and FAO/WHO, 2013). If the value of HQ is less than 1, then the exposed local population is said to be safe, if HQ is equal to or higher than 1, it's considered as not safe for human health, therefore potential health risk occurred, and related interventions and protective measurements should be taken (USEPA, 2013). An estimate of risk to human health (HQ) through consumption of the water samples was calculated using equation 2.2;

$$HQ = \frac{DI}{R_f D_O} \qquad (2.2)$$

Where, R_fD_o is the oral reference dose. R_fD_o is an estimate of a daily oral exposure for the human population, which does not cause deleterious effects during a lifetime (USEPA, 2010). DI is the daily intake of water calculated by the following equation:

$$DI = \frac{Conc.\,of\ HM\left({}^{mg}\!/_{L}\right) \times average\,daily\,\mathrm{int}ake\,of\ water\left(\frac{L}{Day}\right)}{Body\ weight(kg)} \qquad (2.3)$$

Where HM is heavy metal, average daily intake of water by adult and children are 2 L/day and 1 L/day with average body weight for adult and children is 60 kg and 10 kg respectively by WHO (2011).

Table 0-1: Oral reference doses (R_fDo) mg kg-1 day-1 for heavy metals

Trace or Heavy Element	Oral Reference Dose(mg/kg/day)	
	IRIS (US EPA 2013)	FAO/WHO (Codex Alimentarious Commission, (2013)
Fe	-	0.7
Ni	0.02	0.02
Zn	0.30	0.30
Cd	0.0005	0.001
Cr	0.003	0.003
Pb	-	0.004
Mn	0.14	0.014
Cu	-	0.04

2.6.2 Hazard Index (HI)

To evaluate the potential risk to human health through more than one heavy metal, the hazard index (HI) has been developed (USEPA, 1989). The hazard index is the sum of the hazard quotients for all heavy metals, which was calculated by the Eqn (2.3) (Guerra et al., 2010). It assumes that the magnitude of the adverse effect will be proportional to the sum of multiple metal exposures. It also assumes similar working mechanisms that linearly affect the target organ.

$$HI = \sum HQ = HQ_{Cd} + HQ_{Fe} + HQ_{Zn} + HQ_{Pb} + HQ_{Cr} + HQ_{Cu} + HQ_{Ni} + HQ_{Mn}$$

(2.4)

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 SAMPLE COLLECTION

One hundred and seventeen samples of 500 mL bottles of water samples were collected from thirty nine locations. Out of these, thirty samples were collected from boreholes , six samples from hand-dug wells and three samples from surface water. Out of these, seventy eight (78) samples were collected for the analysis of physico-chemical parameters including trace elements and thirty nine (39) samples for the bacteriological or microbial analysis. Three groundwater samples were collected at each site into three types of clearly labelled bottles, two for physico-chemical analyses and the other for bacteriological analyses. Samples were collected from Dome, Kwabenya, Taifa, Abokobi, Pantang and Haatso communities based on geomorphology, flow direction and geological formations obtained from secondary data. The field measurement was conducted within the Municipality between early December 2014 and late January 2015 respectively. The samples were collected early in the morning to noon after it was purged for fifteen minutes to remove all stagnant waters to enable get true representative samples.

The samples were collected directly from the groundwater source, without going through the overhead tank after filtering through 0.45 µm membranes and collected in acid washed, well rinsed polyethylene bottles. For cat-ions, few drops of dilute hydrochloric acid was added to the samples to keep in-situ conditions before transporting to the laboratory whilst for anions, no drop of hydrochloric acid was added. For microbial analyses, sample bottles of and stomacher were sterilized in the Gallenkamp autoclave at a temperature of 121 ^{o}C for fifteen minutes. An indicator tape was placed across the cover of bottles before they were sterilized.

A black strip on the indicator tape signified proper sterilization of the bottle. Petri dishes were also sterilized at 160 ^{O}C for one hour to avoid any contamination during sampling.

Each sample collected was preserved in a light-proof insulated box containing ice-packs to prevent possible alteration of parameters by light and also to ensure that the microorganisms remained viable though dormant. Samples were then transported to the Inorganic Laboratory of the Nuclear Chemistry And Environmental Center for the physico-chemical analysis and Soil and Environmental Sciences Research Center Laboratory of the Biotechnology and Nuclear Agricultural Research Institute for the bacteriological analysis all of Ghana Atomic Energy Commission (GAEC) in Accra. Sampling protocols were strictly observed during sample collection (Claasen, (1982) and Barcelona et al., 1985). Locations of the boreholes were picked by a Garmin eTrex hand-held Global Positioning System (GPS) receiver.

3.2 FIELD ANALYSIS

For all samples collected, parameters such as electrical conductivity (EC), temperature (Temp), pH, total dissolved solids (TDS), turbidity and bicarbonate values were measured in the field. On-site testing was necessary for these parameters since they are likely to change during transport by using multi-parameter HQ40d18 series portable meter. The vessel was thoroughly rinsed with a portion of the sample to be examined and then filled completely. The cell was inserted into the vessel and the various indicated values for TDS, pH, EC and Temperature were read on the meter. Locations of the boreholes were picked by a Garmin eTrex hand-held Global Positioning System (GPS) receiver a water sample location map was generated from the GPS location recorded (Fig. 1.1).

Bicarbonate in the field was measured by titration method. A 25 mL sample was pipetted into a conical flask. Two drops of methyl orange indicator was added to give an initial colour of yellow and the resulting mixture titrated against the standard 0.2M HCL solution until endpoint of orange was reached and titre value recorded. The following equation was used in the calculation

$$Bicarbonate(HCO_3) = \frac{A \times N \times 25{,}000}{1mL\ sample} \tag{3.1}$$

Where A= mL of acid used.

N= Normality of standard acid used.

Turbidity was also measured using a turbidimeter with sample cells, HACH model: 2100P was used. Samples in 1000mL plastic bottles were analysed on the field. The meter was calibrated and the knob was adjusted to read 0.1 before use. The sample was shaken vigorously and poured into the cell to at least two-thirds full. The appropriate range was selected, when the red light came on, the knob was moved to the next range till it was stable, and then the turbidity value was read.

3.3 LABORATORY ANALYSIS

The physico-chemical parameters that were determined are total suspended Solids (TSS), salinity (sal.), apparent colour, true colour, fluoride (F^-), chloride (Cl^-), magnesium (Mg^{2+}), calcium (Ca^{2+}), potassium (K^+), sodium (Na^+), total hardness (TH), sulphate (SO_4^{2-}), nitrate (NO_3^-), phosphate (PO_4^-), the trace element analysed were iron(Fe), cadmium (Cd), zinc (Zn), lead (Pb), chromium (Cr), copper (Cu), nickel (Ni), manganese (Mn), arsenic (As) and the bacteriological parameters that were also determined were total viable count (TVC), total coliform (TF) and faecal coliform (FC). These parameters were measured since they help in making effective inferences from which valid conclusion will be drawn.

To begin with, true colour was determined using the Alpha Platinum–Cobalt standard method. The sample was filtered and poured into the cuvette and placed in the colorimeter. After calibration the result was read. Also, apparent Colour was also determined using the Alpha Platinum –Cobalt standard method. This time the sample without filtration was poured into the cuvette and placed in the colorimeter. After calibration the result was read.

Total Suspended Solids was determined using the Photometric Method. 25 mL of the water sample was pipetted into a cuvette and was shaken to ensure even distribution of dissolved solids. The colorimeter was calibrated and the readings recorded. In addition, total hardness was also determined using EDTA titrimetric method. A 25 mL of the sample was pipetted into a conical flask. To this was added 1.5mL portion of ammonium chloride buffer solution to the aliquot which gave an initial colour of violet and was then followed by the addition of 30 mg eriochrome black T indicator crystal. The resulting solution was titrated with 0.01 M EDTA solution with continuous stirring until the end point colour of blue was reached. The following equation was used in the calculation

$$Total\ Hardness(mg/L\ CaCO_3) = \frac{A \times B \times 1000}{1mL\ sample} \qquad (3.2)$$

Where A=mL of titrant and B=mg CaCO3 equivalent to 1 mL EDTA titrant

Also, salinity concentration was also determined using colorimetric method. A beaker was neatly cleaned with distilled water later rinsed with part of the sample to be determined. An appreciable amount of the sample was poured into the beaker. The probe of the colorimeter is dipped into the beaker and read. Moreso, using Bargentometric method, chloride was determined. 25 mL of the each water sample was pipetted into a conical flask. After which 2 drops of potassium chromate solution was added to the aliquot which gave an initial colour of yellow. It was then titrated against 0.1 M Silver Nitrate ($AgNO_3$) from the burette to an endpoint colour of reddish yellow. Titre values were read and recorded.

Furthermore, calcium was also determined by using EDTA titrimetric method. 5mL of the water sample was pipetted into a conical flask. 2.5 mL of 1 M NaOH was added to the aliquot after which few grains of murexide was added to the aliquot which gave an initial colour of violet. It was then titrated against disodium ethylenediaminetetraacetate dihydrate (EDTA) from the burette to an endpoint colour of purple. Titre values were read and recorded.

Moreover, sulphate determination was by turbidimetric method. 10 mL of the water sample was pipetted into a test tube and 1 mL, 0.5 mL and 0.5 g of acid salt, glycerol and Barium Chloride ($BaCl_2$) solutions were added respectively. It was then shaked for one minute and allowed to stand for 5 minutes. Prepared sample absorbance were read and recorded at a wavelength of 420 nm using the UV spectrophotometer.

Furthermore, AOAC Official method was used in determining nitrate. 5 mL of the water sample was pipetted into a test tube. 1 mL of 30% sodium chloride (NaCl), 5 mL of 6.5 M sulphuric acid (H2SO4) and 0.25 mL of Brucine excluding the blank were added respectively. This was heated for 25 mins at 95ºC and allowed to cool for about 5 mins. Prepared sample absorbance was read at a wavelength of 410 nm using the UV spectrophotometer. Again, ascorbic acid method was employed in the determination of phosphate concentration in the water samples. 10 mL of the water sample was pipetted into a test tube. 2 mL of combined reagent (ascorbic acid + antimony molybdate in the ratio 1 mL: 4 mL respectively) was added. An appearance of blue colour was attained. Prepared sample absorbance was read at a wavelength of 880 nm using the UV spectrophotometer. Also, fluoride concentration was determined by the SPANS method. 10 mL of the water sample was pipetted into a cuvette. 2 mL of SPANS (sodium 2-(parasulphophenylazo)-1, 8-dihydroxy-3, 6-naphthalene disulphonate) was mixed with zirconyl-acid reagent and added to the sample which was placed in the colorimeter. The colorimeter was calibrated and the reading taken.

Moreover, flame photometric method was also employed in determining sodium concentration of the various water samples. Using a 10 mL measuring cylinder, 5 mL of distilled water and 2 mL of lithium standard of 20 mg/L was poured into it and dropped into the tube of the flame photometer. 5 mL of sodium standards of 20 mg/L was poured into the measuring cylinder. After shaking, it was then dropped into the tube and results read. This was done to standardize and calibrate the flame photometer. For actual reading, 5 mL of the sample was added to 2 mL of lithium and dropped into the tube of the machine and results read. Again, flame photometric method was also used to determine the concentrations of potassium in the water samples. Using a 10 mL measuring cylinder, 5 mL of distilled water and 2 mL of lithium standard of 20 mg/L was poured into it and dropped into the tube of the flame photometer. 5mL of potassium standards of 20 mg/L was poured into the measuring cylinder. After shaking, it was then dropped into the tube and results read. This was done to standardize and calibrate the flame photometer. For actual reading, 5 mL of the sample was added to 2 mL of lithium and dropped into the tube of the machine and results read.

However, trace or heavy elements were determined by atomic absorption spectrophotometer (using Fast Sequential Atomic Absorption Spectrometry (AA240FS)) (AAS) method. Digestion of samples for AAS readings was done by using a 100 mL beaker, 5 mL of aqua regia (4.5 mL of Hcl is to 0.5 mL Nitric Acid) was added to 40 mL of the water samples which was then placed on a hot plate at 45 ^{0}C and digested for 3 hours which was covered with a cling wrap. After digestion, it was allowed to cool to room temperature. The side walls of the beaker was washed with distilled water and toped it up to a final volume of 30 mL and then transferred into test tubes for AAS readings (AHPA1995). AAS readings was done by calibrating the AAS machine using known standards for determining the various elements which was then assayed or analysed for, arsenic, magnesium, manganese, iron, copper nickel, lead, cadmium, chromium and zinc under these working conditions in Table 3.1

Table 0-1: Calibration of AAS machine using known standards

ELEMENT	WAVELENGTH(nm)	SLIT WIDTH(nm)	LAMP CURRENT(mA)	FUEL	SUPPORT
Nickel	232.0	0.2	4	Acetylene	Air
Lead	217.0	1.0	5	Acetylene	Air
Arsenic	193.7	0.5	10	Acetylene	Argon
Copper	324.7	0.5	4	Acetylene	Argon
Zinc	213.9	1.0	5	Acetylene	Air
Iron	248.3	0.2	5	Acetylene	Air
Magnesium	285.2	0.5	4	Acetylene	Air
Manganese	279.5	0.2	5	Acetylene	Argon
Cadmium	228.8	0.5	4	Acetylene	Air
Chromium	357.9	0.2	7	Acetylene	Air

For each element read, the lamps were optimized and 3 standards were used to calibrate the AAS machine before actual samples readings were measured. For quality control and quality assurance purposes, blanks were used to check contamination during sample preparation, repeat or duplicate were also carried out to check reproducibility of the method used and finally standards were also used to check the efficiency of the equipment(AAS) used. After the readings or measurement, final concentrations of the various elements were calculated using equation 3.3

$$Final\ Concentration(mg/L) = \frac{Concentration(d.f) \times Nominal\ Volume(mL)}{Sample\ weight\ in\ grams} \tag{3.3}$$

Where d.f = dilution factor

Microbiological analysis was done for total viable count (TVC), total coliform (TC) and faecal coliform (FC). Preparation of Media was done by preparing plate count agar (PCA) in appropriate quantities and then sterilized. The melted agar was tempered in a water bath to 45

^{O}C ensuring that the water level was 1 cm above the level of the medium in the bottles. Working area was clean with a suitable disinfectant and duplicate petri plates clearly marked.

Preparation of serial dilution (10-1 or 1/10 dilution) was also done by aseptically weighing 10 mL of the sample into 90 mL of the required diluent. Each dilution bottle was agitated to re-suspend material that may have settled out during preparation. One (1mL) of each diluent was transferred into well labelled sterile petri dishes for plate count agar (PCA), violet red bile agar (VRBA) and EMBA that is double trial for each dilution and plates were poured not more than 15 minutes after preparation of dilution at 45 ^{O}C PCA and VRBA were poured respectively. Plates were swirled gently and left for 15 minutes to solidify. Four (4) mL of PCA, VRBA and EMBA was added respectively to plates (2nd layer) and left to solidified (to be sure that the entire plates were covered). Plates were incubated at 37 ^{O}C±1 for 24 – 48hrs. Results were checked on daily basis up to 48 ± 4hrs.Colonies were counted promptly after the incubation period using the colony counter with plates of 30-300 colonies (including pinpoint colonies) counted. With counts that do not fall within this range, plates that fall nearest to the 30-300 range were selected and counted.

Plates at only one dilution containing countable colonies were used.

Counts were calculated using equation 3.4

$$N = \frac{C1 + C2}{2VD} \qquad (3.4)$$

Where, V= dilution volume

D= dilution factor where plates were counted

Aerobic Colony Count (ACC or APC), using the formula: N = A x D, where

N is the Colony Forming Unit (CFU) per g (mL) of product, CFU/g (mL), A is the average count per plate, and

D is the respective dilution factor.

3.4 HANDLING AND INTERPRETATION OF RESULTS

In this study, SPSS version 18.0, Microsoft excel, ArcGIS version 10.2, and AQUACHEM were some of the softwares used in the data processing and analysis. Statistical methods were used to interpret groundwater sample data. Though they do not establish cause and effect relationships, but are useful in recognizing in advance the factors that controls the composition of groundwater. The data were log –transformed to normally distributed data. The results were then tabulated and displayed in graphical forms such as box and whisker plots, histograms, scatter plots and pie chart to examine the physical and chemical properties of the water.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 WATER QUALITY

Groundwater quality often depends on the composition of recharge water, interaction between the water and the soil, soil-gas and rock with which it comes into contact in the unsaturated zone and the residence time and reactions that take place within the aquifer (Freeze and Cherry,1979; Hem, 1989; Fetter,1994; Appelo and Postma, 2005).

In this chapter, the physico-chemical and microbial parameters of the water samples are presented and discussed. A statistical summary of the quality parameters determined for each sample is presented and displayed visually in box and whisker plots. Interpretation of the available data is discussed in the subsequent sections, based on the analytical results in comparison with relevant literature.

Table 4. 1: Summary of field and analytical data of the physico-chemical parameters in the study area

PHYSICAL PARAMETERS	MINIMUM	MAXIMUM	MEAN	WHO (2011)	WRC (2003)
Ph	4.35	8.97	6.40	6.5-8.5	6.0-9.0
Temp(^{O}C)	27.3	34.5	29.42	-	-
EC (µS/cm)	334	3999	1832.10	700	1500
TDS (mg/L)	166	2000	915.72	1000	0-450
TSS (mg/L)	0	57	2.84	0	500
HCO_3^- (mg/L)	8	2000	701.49	380	-
Turb (FAU)	0	66	4.18	5	0-5
Sal (ppt)	1.2	71	8.24		

Table 4. 2. continued

PHYSICAL PARAMETERS	MINIMUM	MAXIMUM	MEAN	WHO (2011)	WRC (2003)
T C (Plat.Cobalt unit)	0	95	5.97	5	-
F^- (mg/L)	0.08	2.09	0.90	1.5	0-1.0
Cl^- (mg/L)	149.5	3798.82	627.91	250	0-100
Na^+ (mg/L)	87.3	2186	586.31	200	0-100
K^+ (mg/L)	3.2	502	42.11	-	0-50
TH ($mgCaCO_3/L$)	200	6000	1334.70	500	0-50
NO_3^- (mg/L)	< 0.001	1.97	1.15	50	0.2
PO_4^{2-} (mg/L)	< 0.001	0.924	0.095	250	
SO_4^{2-} (mg/L)	7.10	382.26	95.73	200	0-200
Ca^{2+} (mg/L)	3.2	379.2	80.40	200	0-32
Mg^{2+} (mg/L)	0.76	1.99	1.53	-	0-30

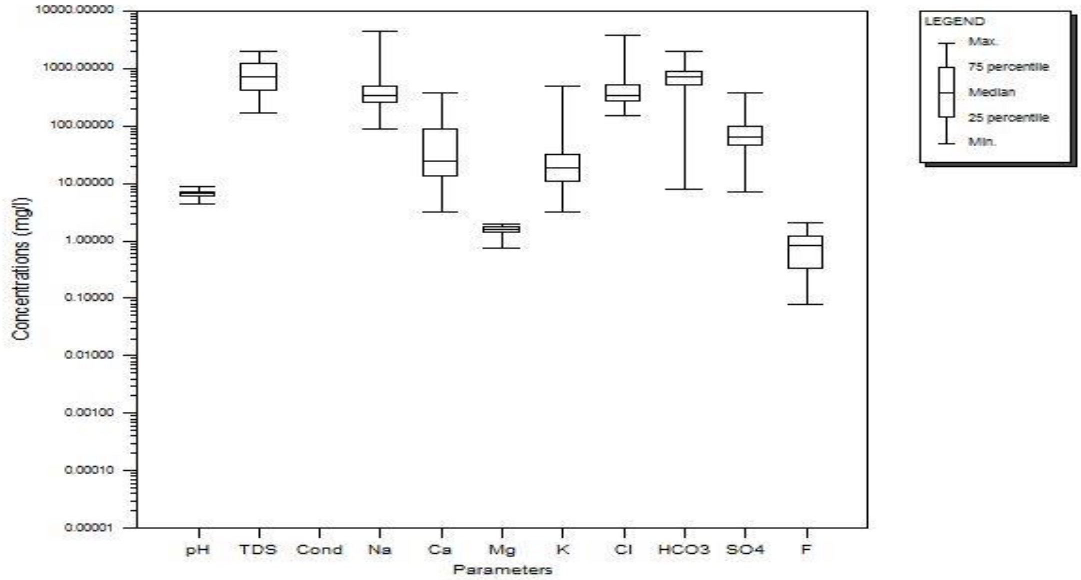

Figure 0-1: Box and Whisker plots of major ions, pH, conductivity, temperature and TDS

4.1.1 Physical Parameters of Water

Generally, pH values of groundwater samples ranged from 4.35 to 8.97 as shown in Table 4.1. pH of surface water (SW) ranged from 6.88 to 8.50 with hand dug well between 5.17 to 7.53. Thirteen samples representing 43% of boreholes fell within the WHO (2011) guideline value of 6.5 to 8.5, whiles seventeen water samples representing 57% fall below 6.5 which indicates that the water was slightly acidic to slightly alkaline and can cause acidosis since according to Hem (1989) and David and DeWiest, (1966) mentioned that acidic waters occur when the pH is lower than 4.5. These variations in pH could be due to the presence of dissolved bicarbonates, hardness, alkalinity etc. present in the water sample which are known to affect pH of most waters (Chapman, 1992). The acidic nature of samples may be due to the presence of CO_2 within the soil zone from microbial respiration and other natural biogeochemical processes (Yankey et al., 2011; Hounslow, 1995; Langmuir, 1997). Acidity increases the capacity of the water to attack geological materials and leach toxic trace metals into the water making it potentially harmful for human consumption.

This is evident in site KA5, which recorded the least pH of 4.35 whilst site PA3 (shallow well 20 m downside of the Abokobi dumpsite) recorded 8.97 with high dissolved ions which might be due to leachate from the dump site at Abokobi, runoff from irrigation farms at Haatso and other parts in the Municipality. In the study area, however the numbers of boreholes that have shown slightly acidic characteristics are significant and thus represent the overall groundwater chemistry. In this regard, the quality of the groundwater is not good for drinking and domestic uses. The pH values of water from the study area slightly acidic to alkaline as shown in Figure 4.2.

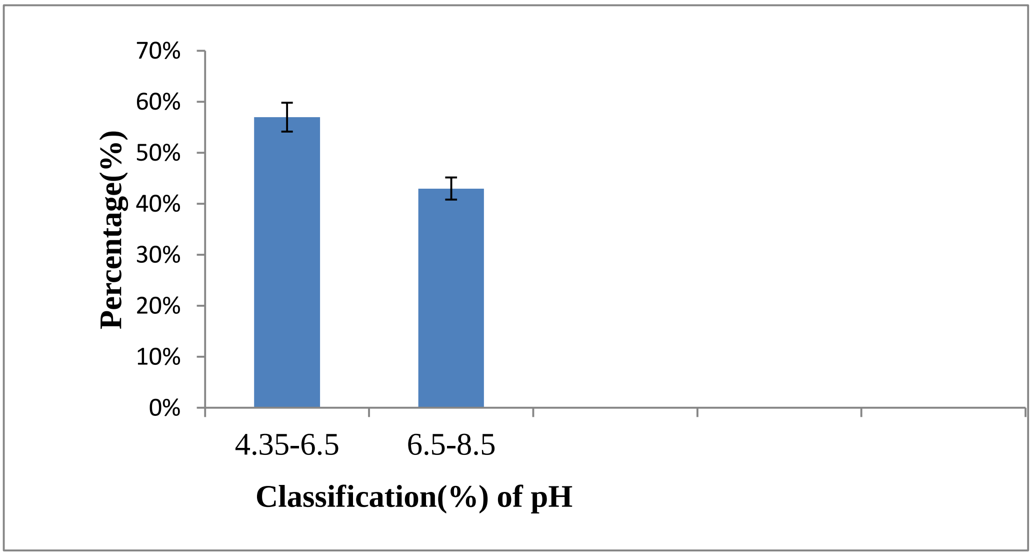

Figure 0-2: Percentage classification of pH of borehole water samples in the study area

In this study, the measured temperature values of the water samples were between 27.3 ºC to 34.5 ^{0}C with a mean of 29.42 ^{0}C (Table 4.1). The difference in temperature could be attributed to the variation in sampling time. The lowest temperature of 27.3 ^{0}C was recorded at Abokobi (ABAH6) which is a surface water and the highest temperature of 34.5 ^{0}C was recorded at Pantang (PA3) which is a shallow hand dug well few meters downside of the Abokobi dumpsite which might be collecting leachate from the dumpsite. Temperature of drinking water is often not a major concern to consumers especially in terms of drinking water quality. The quality of water with respect to temperature is usually left to the individual taste and preference and there are no set guidelines for drinking water temperature.

Electrical conductivity (EC) gives an account of all, the dissolved ions in solution. This depends on the ionic strength of the water sample. Thus the higher the EC, the higher the levels of dissolved ions in the sample and could imply high mineralization (WRC, 2003). Electrical conductivity values varied from 334 µS/cm to 3999 µS/cm for boreholes as shown in Table 4.1. Conductivity levels of the groundwater sampled as shown in Figure 4.1 indicate that all sites were above the WHO guideline limit of 1500 µS/cm except some eight sample sites namely, AS4, DA9, KA5, KA6, KA7, PA2, TA2 and TH1 with values 460 µS/cm, 534 µS/cm, 435 µS/cm, 401 µS/cm, 475 µS/cm, 334 µS/cm, 621 µS/cm and 622 µS/cm respectively were within the WHO and WRC limit. Surface water had conductivity ranges between 1185 µS/cm and 1568 with hand dug wells ranging between 622 µS/cm and 3999 µS/cm. Generally, conductivity of clean water is lower but as it moves down the earth it leaches dissolves ions from the soil and also picks up organic materials from biota and detritus (Ferrar, 1989).

The high conductivity recorded could be as a result of dissolution of rocks minerals, domestic effluent discharges and surface run-off from the gutters and the irrigation fields which might have increased the concentration of ions. At site PA3 which also recorded 3999 µS/cm could be coming from leachate moving from the dumpsite in this shallow hand dug well .This indicates that the water has a marked salty taste. Scale may be expected on plumbing appliances and consumption of water does not appear to produce adverse health effects in the short term (WRC, 2003). Generally the conductivity values recorded for various sampling sites pose potential health risk for consumers.

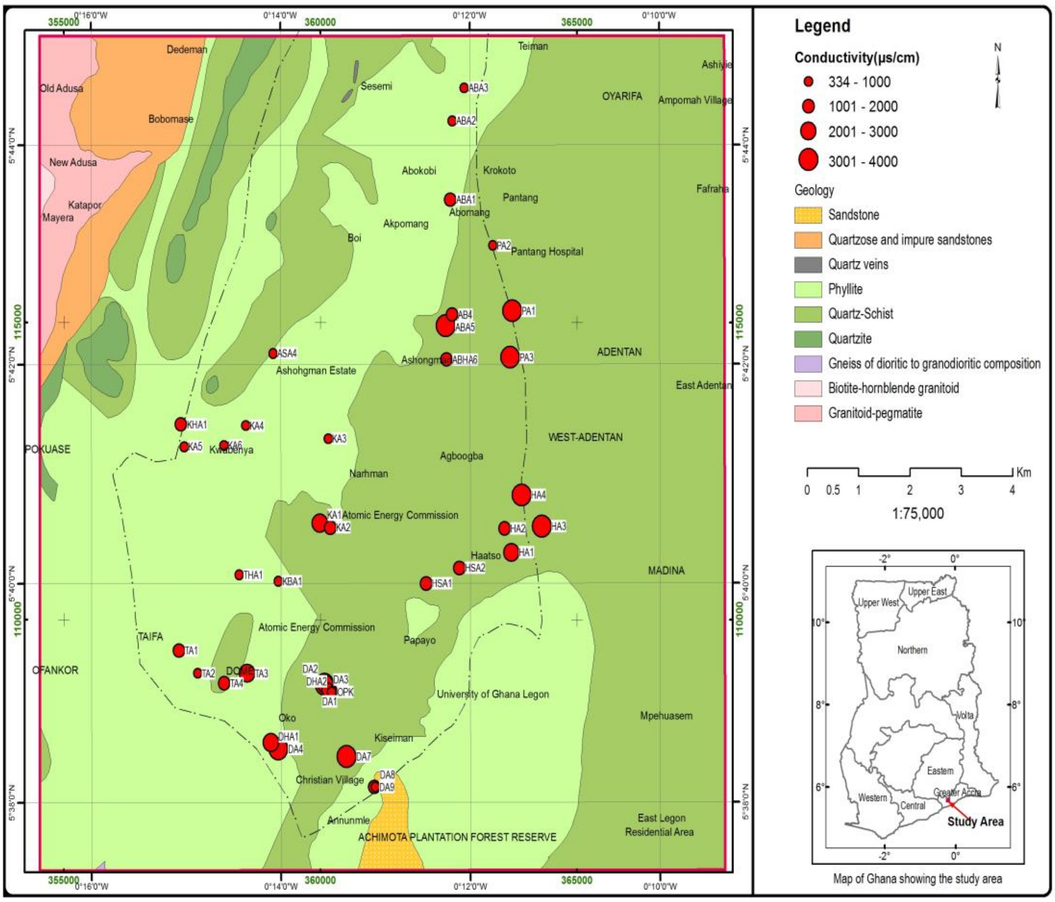

Figure 0-3: Visual comparism of geology and EC in the study area

The value for TDS varied from 166 mg/L to 2000 mg/L. Sixty three (63 %) of water samples had TDS in the study area within the WHO safety standard limit of 1000 mg/L suggesting these samples can be used as drinking water without any health risk with 37 % of water samples above the WHO guidelines values suggesting these samples cannot be used as drinking water.

TDS concentrations values which are shown in Table 4.3 showed that Nineteen (19) sites were within the WHO safety guideline limit with Eleven (11) sampling sites above the WHO guideline suggesting these samples cannot be used as drinking water. Surface water had TDS range of 593 mg/L to 782 mg/L whiles hand dug wells recorded TDS range 312 mg/L to 2000 mg/L here also site PA3 as usual also recorded the highest TDS 2000 mg/L. High TDS in water may produce bad taste, odour and colour and may also induce unfavorable physiological reactions in the consumer (Spellman and Drinan, 2000). To ascertain the suitability of groundwater for any purposes, it is essential to classify the groundwater depending upon their hydrochemical properties based on their total dissolved solid (TDS) values (Fetter, 1990) which are presented in Table 4.3. According to the standard TDS classification (Fetter, 1990) the groundwater in the study area falls under the category of fresh water.

According to MacCutcheon et al. (1983), the taste of water with TDS level less than 600 mg/L is generally considered to be good whereas water with TDS greater than 1200 mg/L becomes increasingly unpalatable. In water samples, most of the matter is in dissolved form and consists mainly of inorganic salts, small amounts of organic matter and dissolved gases, which contribute to TDS. Therefore, the possible sources of TDS in the study area may include agricultural runoff, numerous washing bays and from geology.

Table 0-1: Classification of groundwater based on TDS of the study area (Fetter, 1990)

Category	Total Hardness (mg/l)	No. of samples with percentages.
Fresh water type	< 1000	26(66.7%)
Brackish water type	1000 – 10000	13(33.3%)
Saline water type	10000 – 100000	Nil

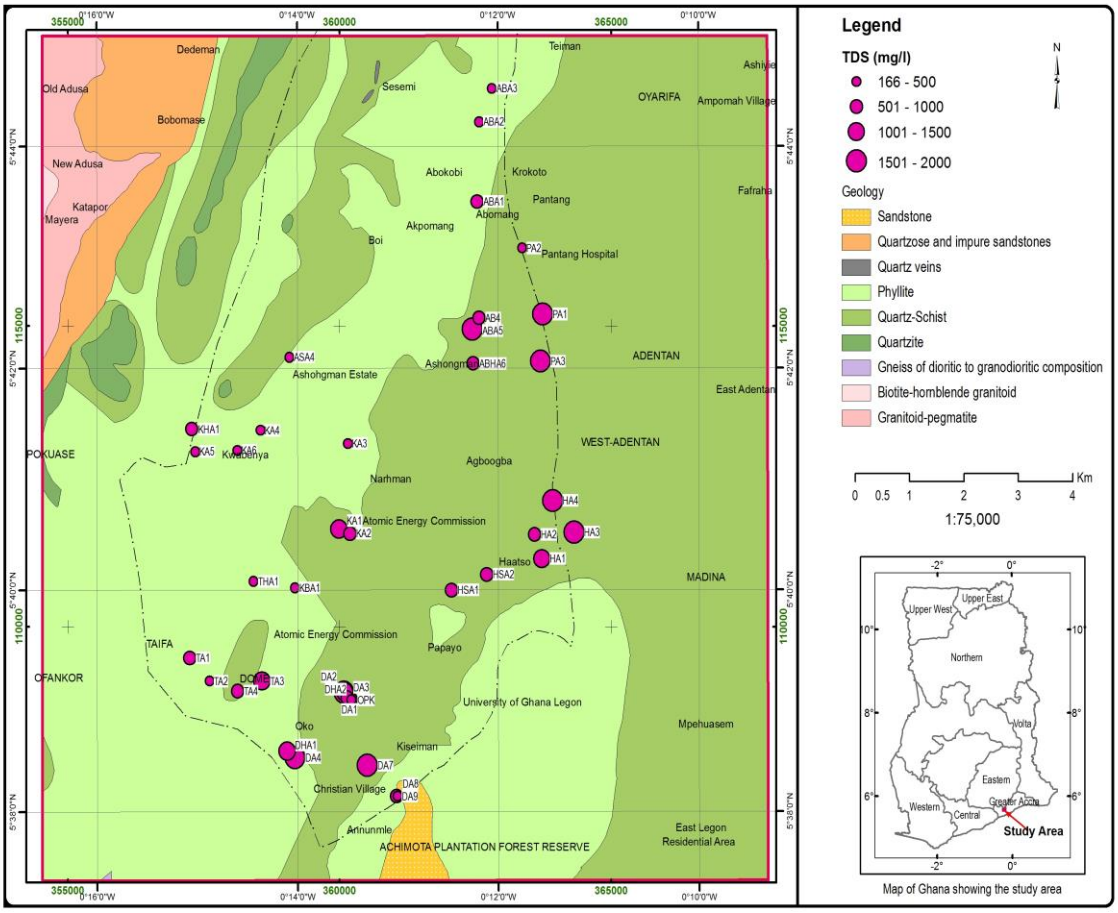

Figure 0-4: Visual comparism of geology and TDS in the study area

Turbidity is caused by the presence of suspended matter, such as clay; silt, finely divided organic and inorganic matter, plankton and other microscopic organisms (WRC, 2003). Turbidity values ranged from 0 to 66 FAU as shown in Table 4.1. The turbidity values showed that all the values were within the WHO safety guideline limit except five sampling sites (ABA5, KA7, HSA1, HSA2, PA3) that, showed significant turbidity values recording 49, 66, 10, 9, and 23 FAU respectively were above the WHO limits. This indicates that the water at the five sampling sites that were above the WHO carried an associated risk of disease transmission due to infectious disease agents and chemicals adsorbed onto particulate matter. In addition, turbidity was obvious and had aesthetic effects on appearance.

Sample KA7 had the highest value of 66 FAU with aesthetic appearance of brown colloids which might be due to the high dissolution of iron from siderite at the sample site in Kwabenya. At sites HSA1 and HSA2 are surface water recording turbidity values 10 and 9 respectively. This might be due to the presence of suspended matter, such as clay; silt, finely divided organic and inorganic matter, plankton and other microscopic organisms in the surface water (stream) at Haatso near the irrigation site. At site PA3 turbidity value was 23 FAU which might be due to leachate from Abokobi dump site which might have also found its way as a result of advection and diffusion into the shallow well and borehole at it site AB5 (49 FAU).

Bacterial growth in casing pipes due to improper maintenance and anaesthetic surroundings also account for higher turbidity (Sawyer et al., 2000). Inorganic nutrients such as nitrogen and phosphorus present in agricultural runoff stimulate the growth of algae, which also contributes to turbidity (Sawyer et al., 2000).

According to WHO standards for drinking water, the colour limit should be 25 Plat.Cobalt unit. All the water samples were within the WHO (2011) limit except 4 sites namely ABA5, KA6, HSA1 and HSA2 with values 262 Plat.Cobalt unit, 314 Plat.Cobalt units, 97 Plat. Cobalt unit and 93 Plat.Cobalt unit respectively (Table 4.3). These variations in colour at site HSA1 and HSA2 might be as result of samples been taken from surface water (stream) at Haatso irrigation site resulting from fertilizer runoff from the irrigation farm. At site KA6 might be coming from iron dissolution into the borehole at Kwabenya whilst site ABA5 might be from possible leachate from the dumpsite. Colour in natural water usually results from the leaching of organic materials and is primarily the result of dissolved and colloidal humic substances.

According to WHO standards for drinking water, the colour limit should be 5 Plat.Cobalt unit. All the water samples were within the WHO limit except 6 sites namely ABA5, KA6, ABHA6, HSA1 and HSA2 with values 42 Plat.Cobalt unit, 95 Plat.Cobalt unit, 13 Plat.Cobalt unit, 24 Plat.Cobalt unit and 25 Plat.Cobalt unit respectively (Table 4.3).

Colour in natural water usually results from the leaching of organic materials and is primarily the result of dissolved and colloidal humic substances, primarily humic acid and fluvic acid (WRC, 2003). Presence of colour at site ABA5 and ABHA6 might be as a result of runoff and household waste in the stream at ABHA6 with site KA6 could be dissolution of iron from siderite in Kwabenya community. Colour for site HSA1 and HSA2 might be due to runoff from the irrigation site and Haatso community into the receiving stream. Colour is also strongly influenced by the presence of iron and other metals. However the overall colour content of the samples analysed do not pose any health threat to those that use the water (APHA, 1995).

Hardness is a term that is used to describe the resistance of water to produce lather from soap. It is normally expressed as the total concentration of Ca^{2+} and Mg^{2+} as milligram per litre equivalent $CaCO_3$ (Todd, 1980). Total Hardness of water may not have any health implications but may affect the taste of water as well as influence its lathering ability when used for washing. Total Hardness of the water samples ranged from 200 $mgCaCO_3/L$ to 6000 $mgCaCO_3/L$. The WHO recommends a standard safety limit of 500 $mgCaCO_3/L$ hardness in drinking water. The classification of groundwater based on TH (Table 4.3; Fig. 4.3) shows that two boreholes precisely in Kwabenya (200 $mgCaCO_3/L$) and Pantang (220 $mgCaCO_3/L$) representing 5% of recorded total hardness levels between 151 to 300 mg/l and could thus be classified as hard with 95% of the rest of the boreholes within the range of very hard. Surface water total hardness was between 600 $mgCaCO_3/L$ to 700 $mgCaCO_3/L$ with hand dug wells ranging from 600 $mgCaCO_3/L$ to 1600 $mgCaCO_3/L$.

The Total Hardness values showed that almost all sampling sites were above the WHO guideline values with exceptionally high values recorded at sites DA8, DA7, DA4 with values of 5500 $mgCaCO_3/L$, 3400 $mgCaCO_3/L$ $mgCaCO_3/L$ and 6000 $mgCaCO_3/L$ all in Dome community. Only 4 sites (TA1, TA2, KA6, PA3) in Taifa, Kwabenya and Pantang respectively recording 400 $mgCaCO_3/L$, 400 $mgCaCO_3/L$, 220 $mgCaCO_3/L$ and 200 $mgCaCO_3/L$ respectively were within the safety guideline limits. The solubility of salts is a function of temperature. Hence, the values for 35 sample sites were higher since the salts might have been solubilized. In addition, the higher value could be due to increased anthropogenic activities, e.g. farming using fertilizers at the irrigation sites, improper disposal of household waste and use of detergents at the various washing bays.

Table 0-2: Classification of groundwater in the study area on the basis of total hardness (Fetter, 1990)

Classification	Total Hardness(mg/L)	No. of samples with percentages
Soft	<75	Nil
Moderately Soft	75-150	Nil
Hard	150-300	2(5%)
Very Hard	>300	37(95%)

Dissolved solids comes about as a result of weathering of rocks, soil and dissolving lime and other salts sources as water percolates through them. Groundwater quality changes as the water flows through the subsurface, geological environment increasing dissolved salts and major ions (Jain et al., 1997). Increase in the concentration of dissolved salts such as sulphate, chlorides, and bicarbonates of calcium, magnesium and sodium in the groundwater attributable to both natural as well as human induced factors, leads to the process of salinisation (Salama et al.,1998). As salinity increases, the proportion of all these salts increases.

Generally, salinity values for boreholes range from 1.2 ppt(part per thousand) to 71 ppt. For surface water salinity values was between 4.10 ppt to 4.80 ppt and hand dug wells salinity concentration was between 2.10 ppt to 7.10 ppt. Induced salinisation is caused by the mismanagement of irrigation i.e. human activities (Hem, 1991). TDS indicate the general nature of water quality of salinity. Hem, (1991) has classified the water into four categories on the basis of TDS. It is observed that in the study area twenty six sites (66.7%) were all below Hem classification of salinity hence referred to as fresh water type. Only thirteen sites (33.3%) were above the classification limit hence referring to it as slightly saline.

Table 0-3: Salinity classification of groundwater in the study area on the basis of TDS (Hem, 1991)

Category	Total Hardness (mg/l)	No. of samples with percentages
Fresh Water	< 1000	26 (66.7%)
Slightly saline	1000 – 3000	13 (33.3%)
Moderately saline	3000 – 10000	Nil
Very saline	> 10000	Nil
Brine	>35000 mg/l	Nil

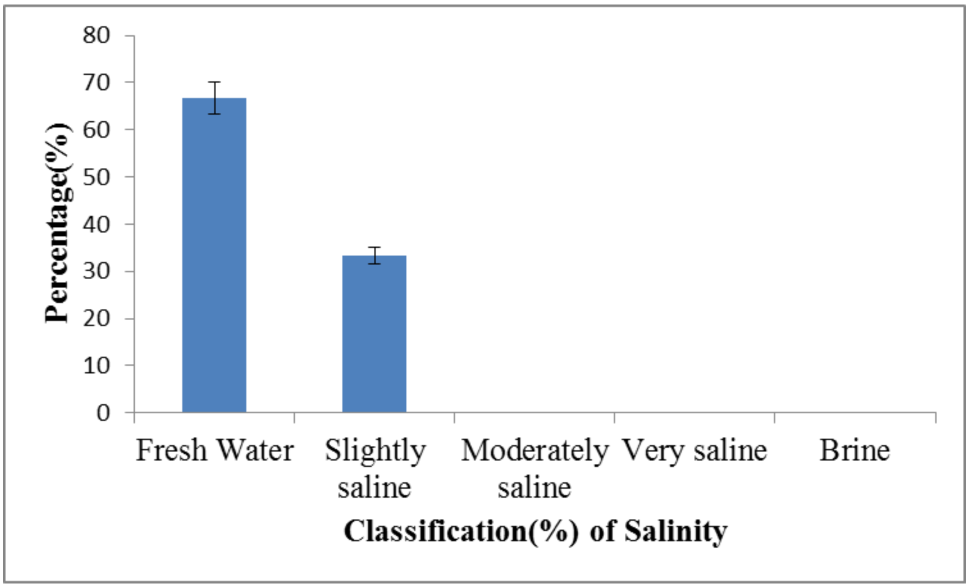

Figure 0-5: Percentage classification of salinity in the study area (Hem1991)

The thirteen sites having been categorized slightly saline might have been possibly due to contamination of the sites by the intensive irrigation practices and excess use of fertilizers in most irrigated farms and households in the study area.

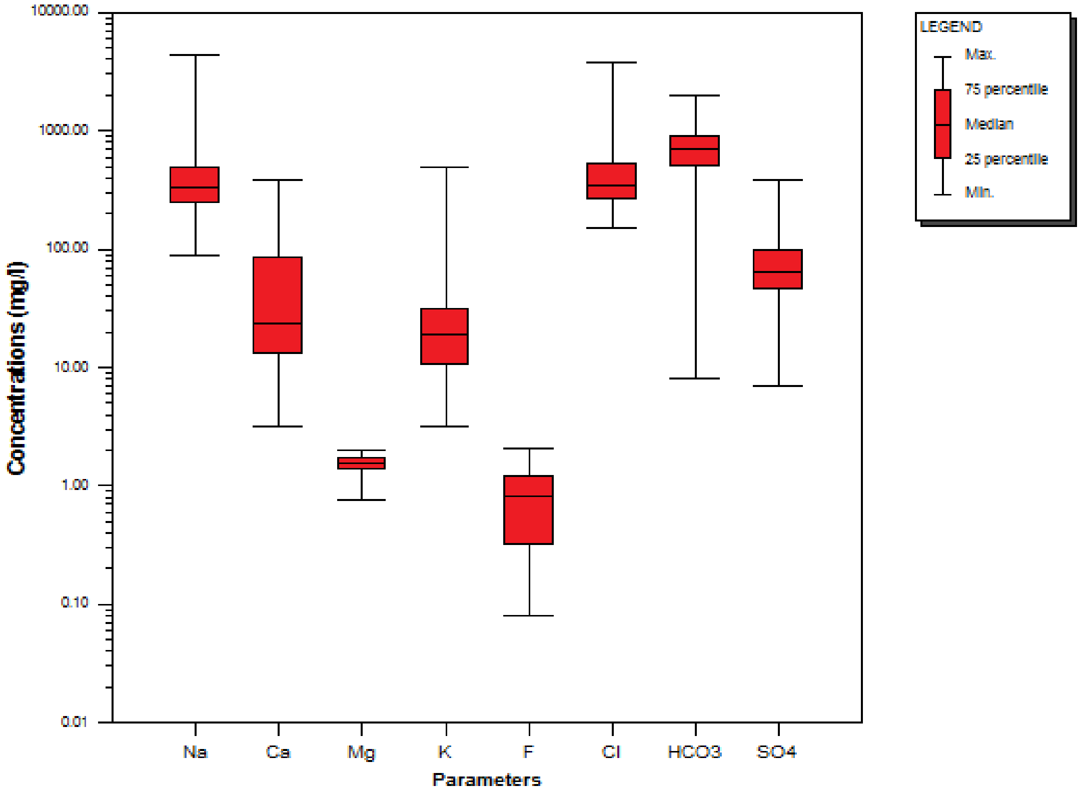

Figure 0-6: Box plots of major ions in the study area

The waters in the study area exhibited and overall ionic dominance pattern of Na^+ > Ca^{2+} > K^+, > Mg^{2+}, for the cations whilst the anion also displayed ionic pattern of HCO_3^- > Cl^-, > SO_4^{2-}

4.2 FACTORS INFLUENCING OBSERVED TRENDS IN THE HYDROCHEMISTRY AND GENERAL GROUNDWATER QUALITY OF THE STUDY AREA

In this study, the PCA analysis was conducted with the SPSS-18.0 software. The extracted PCs explain the overall outcome of the underlying processes that influence groundwater quality in the aquifer. In other words, each PC corresponds to a specific type of groundwater contamination.

It was assumed that the pollution sources are independent of each other. Varimax rotation, which yielded the most consistent results, was used in the factor analysis. The results of the PCA using Kaiser Criterion and varimax rotation resulted in three components, which accounted for 52.7% of the total variance and the rotated component matrix is as shown in Table 4.5

Table 0-4: Rotated Component Matrix and % Variance Of PCA

	Component		
	1	2	3
pH	.397	.392	.287
EC	.910	.241	.092
TDS	.910	.242	.091
TSS	.023	.276	-.260
Sal	.383	.007	.352
HCO3	.123	-.312	.031
F	.492	-.071	.369
Ca	.821	-.188	-.060
Cl	.882	-.078	.025
Na	.505	.791	.052
K	.346	.441	-.067
TH	.693	-.248	.023
NO3 -	.070	.905	.046
PO4 -	.001	.874	-.014
SO4-	.547	.559	.014
Mg	.779	.259	.070
Fe	-.194	.096	-.456
Cd	-.134	.358	-.355
Zn	.042	.935	.013
Pb	-.182	-.072	.490
Cr	.069	-.005	.866
Cu	-.027	.235	.826
Ni	-.059	.254	.181
Mn	-.089	-.070	-.251
% of Variance	23.1	19.0	11.0

Component 1 accounts for 23. 1%, of the total variance and is characterized by very high loadings of electrical conductivity (EC), total hardness (TH), total dissolved solids (TDS), chloride (Cl^-), sulphate (SO_4^{2-}), sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}). Na^+, Ca^+, Cl^- and Mg^{2+} show positive or high loadings under Component 1 could be possibly representing geochemical process involving the dissolution of feldspar group of minerals and other silicate minerals such as hornblende, chlorite, muscovite, illite and biotite which are found in the lithologies of the study area. This also shows that EC in the groundwater is mainly influenced by the contribution from Mg^{2+}, Ca^{2+}, Cl^- , Na^+ and SO_4^{2-} . Component 1 is accordingly defined as the natural or geogenic factor.

Component 2 explains 19.0 % of the total variance and is mainly associated with very high loadings of, Na^+ and SO_4^{2-}, NO_3, phosphate (PO_4) and zinc (Zn) likely reflecting a common source for these elements which are typically related to contamination from human induced activities, that is, as agricultural runoff from the irrigation farms, human or animal wastes from open defaecation, dumping of household waste into streams including, septic tanks effluent leaking into groundwater and dissolution of zinc from taps and zinc plated metals at the dumpsites in the study area. Component 2 is suitably assigned as the anthropogenic factor of agricultural nature.

Component 3 contributes 10.6 % of the total variance and is contributed by chromium and copper reflecting a common source for these metals which might be of anthropogenic nature. Chromium and copper might be coming from leachate from waste disposal dumps, metal taps, pumps of borehole which are plated with chromium in the study area. Component 3 is also duly characterized the anthropogenic factor pointing to waste disposal dumps.

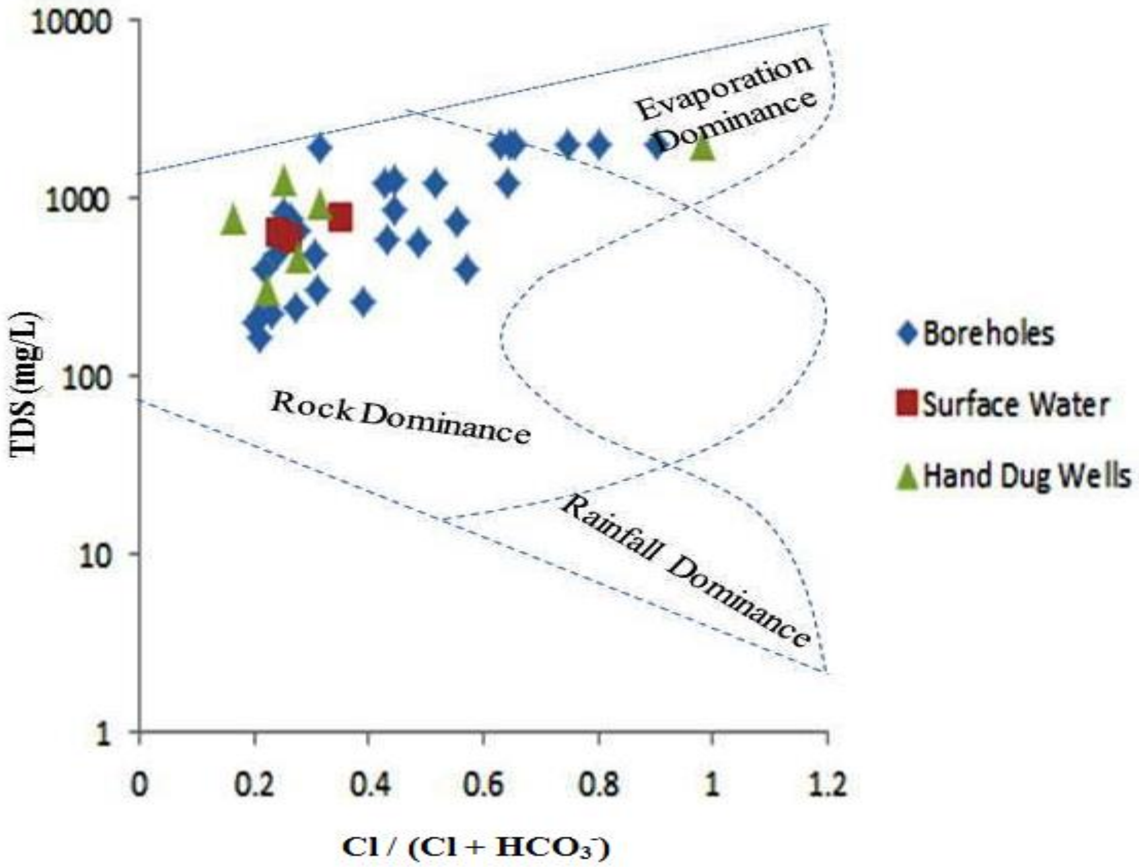

Figure 0-7: Gibbs diagram

Various factors such as the geology of an area, climate and atmospheric depositions control groundwater hydrochemistry. Various works by Ganyaglo et al. (2010), Yidana et al. (2010), Kortatsi (2006) and Jalali (2007) have applied the relationship that exists between anions and

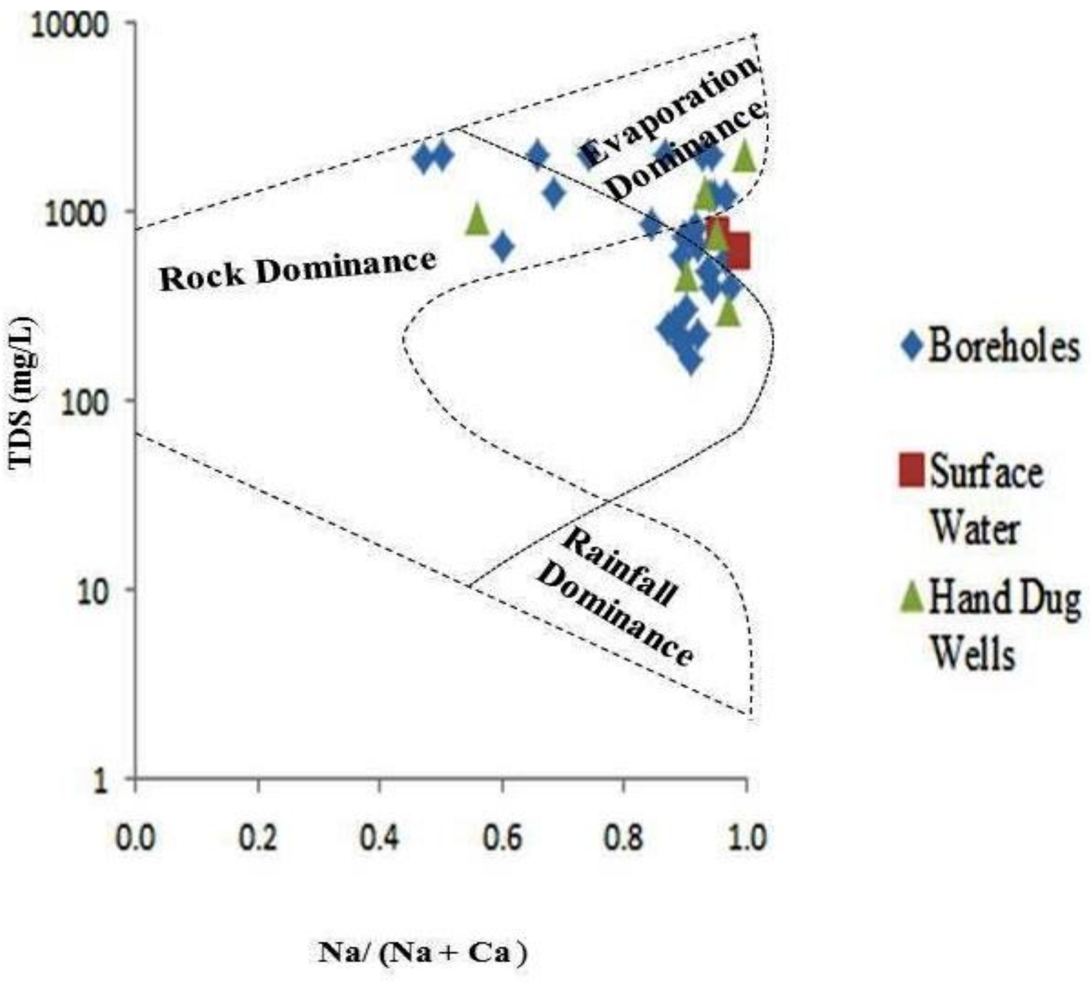

Figure 0-8: Gibbs diagram

cations to identify their possible origin in water. The Gibbs plot (1970) is one of several plots used to determine the possible factors controlling groundwater hydrochemistry in an area. Figure 4.6 shows that most of the major ions plot in the region of rock dominance. However, few of the groundwater samples plots in the evaporation-crystallization dominance zone. This reveals that rock weathering is the major possible hydrogeochemical processes regulating the groundwater hydrochemistry in the study area.

4.3 HYDROCHEMICAL FACIES

Groundwater is generally classified into facies depending on the dominant ions present and the piper diagram is one of such diagrams for this classification. Figure 4.12 shows the Piper (1944) trilinear plot of the groundwater in the study area. Three hydrochemical facies are identified namely; Na-Cl, Na-HCO_3 and Na-HCO_3-Cl (which happens to be a mixed water type).

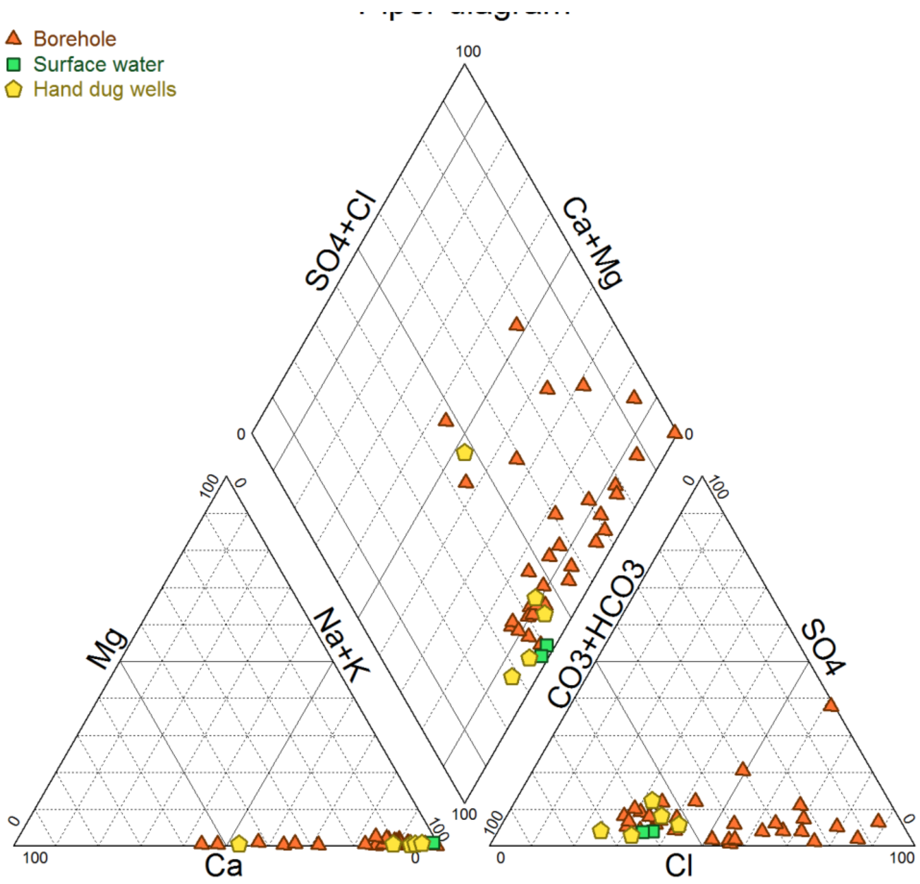

Figure 0-9: Piper trilinear plots showing the various water types in the study area.

The major water types identified in the area are Na-Cl, Na-HCO_3 and Na-HCO_3-Cl and these occupy approximately about 96 % of the water samples in the study area. The predominant rock type as identified in the study area consists mainly of alternating bands of massive basic and acidic gneisses, schist, migmatite, granite-gneiss quartzites, phyllites, quartz-schists, sericite-schists and to a lesser extent shale and siliceous limestone (Holm,1974). The minerals contained in these rocks include plagioclase feldspars (particularly Albite), hornblende, muscovite, illite and chlorite. The primary source of most sodium in natural water is from the release of soluble products during the weathering of the plagioclase feldspars (Davis and DeWiest, 1966; Chapelle and Knobel, 1983; Meisler et al., 1984).

It may be possible that the plagioclase feldspars (particularly Albite) decomposed to release Na^+ in the groundwater. Cation exchange may also play a vital role in the Na contents of the water samples. The bicarbonate in the groundwater could be from the soil zone, by dissociation of carbonic acid ($H_2CO_3^-$) generated by the reaction of CO_2 with H_2O (acid hydrolysis). Weathering of silicate minerals also acts as an important CO_2 sink (Chapman, 1992; Appelo and Postma, 1996). The Cl may be from chlorite as well as anthropogenic sources including human sewage, livestock waste and synthetic fertilizer (primarily KCl) especially from the hand dug wells and surface waters.

4.4 MICROBIOLOGICAL QUALITY OF GROUNDWATER IN THE STUDY AREA

The result of mean microbial quality of the groundwater samples used for the study is presented in Table 4.6.

Table 0-5: Mean microbiological quality of water samples from the study area

	Water sources		
Microbial load (cfu /mL)	HDW	BH	SW
Total Viable Count	1203	1515	4013
Total Coliform	556	415	2540
Faecal Coliform	258	62	1410

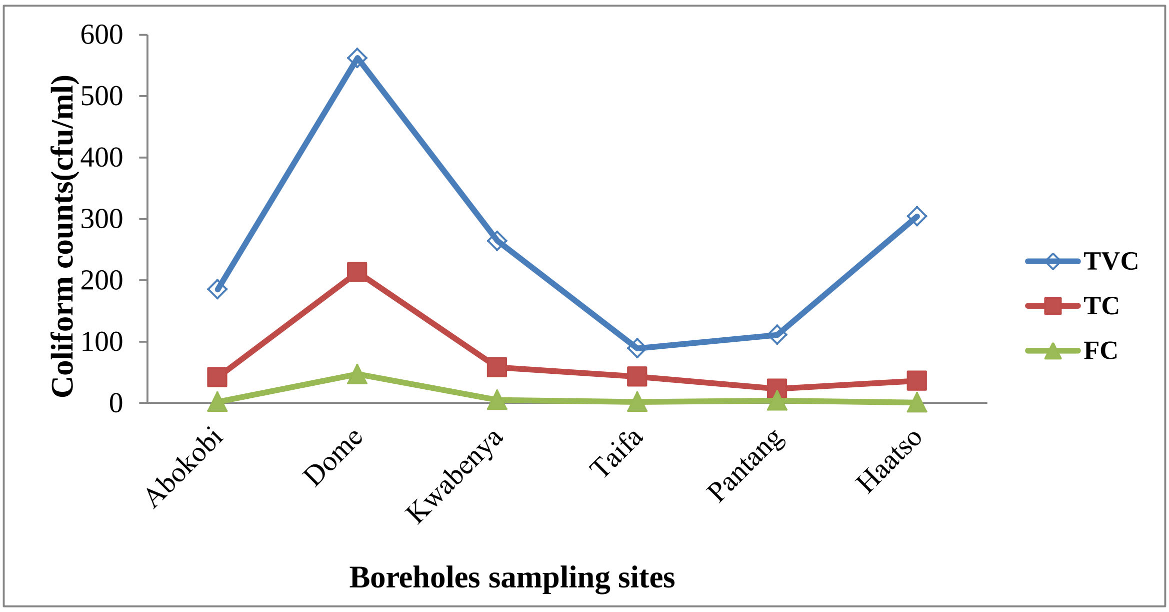

Figure 0-10: Counts of TVC, TC and FC in the study area.

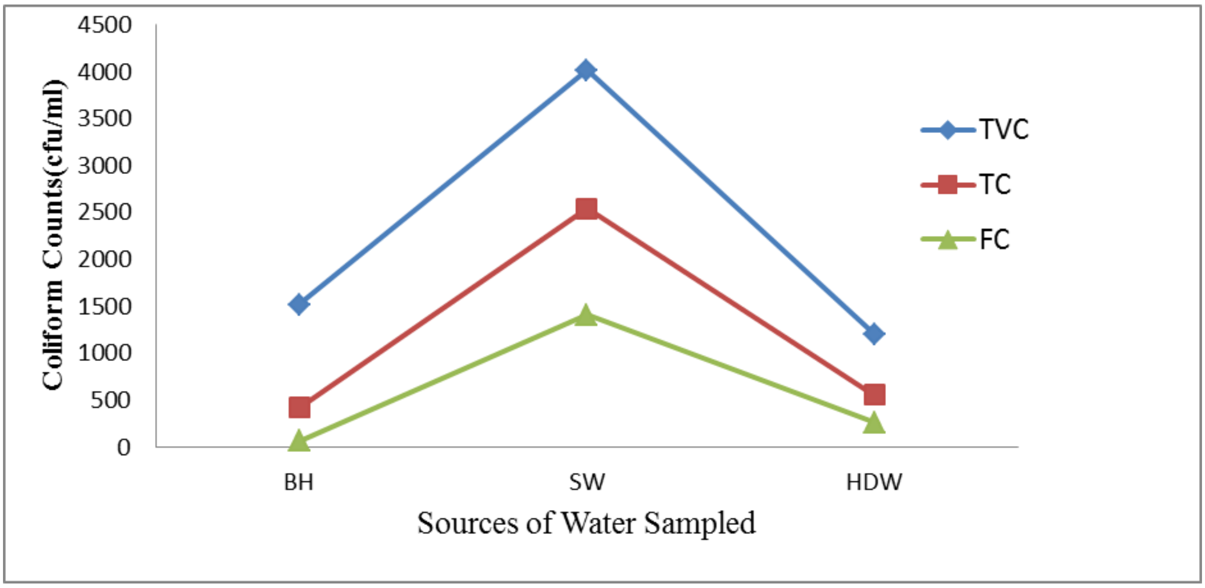

Figure 0-11: Counts of TVC, TC and FC of sources of water sampled in the study area

Total Viable Count (TVC) is not a specific micro-organism but rather a test which estimates total numbers of viable (for the purposes of this study viable means living) individual micro-organisms present in a set volume of sample. The TVC count may include bacteria, yeasts and mould species. The test gives a reading for all bacteria present but not what type of bacteria.

All water types had counts for TVC in them as shown in (Table 4.12 and 4.13). The bacteria may simply not be pathogenic since there are different types of bacteria present in the samples hence the needs to do further test of total coliform counts.

Pollution indicator bacteria (Total Coliforms)(TC) were all above the WHO limit of 0 cfu/100mL. TC counts for boreholes ranged between 0 cfu/mL to 1225 cfu/mL. TC counts for surface water recorded 1510 cfu/mL to 3600 cfu/mL with TC for Hand dug well registering 0 cfu/mL to 2001 cfu/mL. The high T C counts of all of the water types can be attributed to various anthropogenic activities such as poor environmental sanitation in the various communities, the indiscriminate defaecation along the banks of the stream at Haatso and Abokobi. Not only that, improper disposal of household waste, improper borehole development technique collecting household waste into the boreholes whenever it rains, location of septic tanks near the boreholes due to lack of space, leaking septic tanks due to improper designs, building on old refuse dump site in Dome may be leaching effluent into boreholes, runoff from animal waste into water types (WRC,2003). These values indicate significant and increasing risk of infectious disease transmission when the water is used for domestic purposes hence generally 98% of the water samples are considered not safe for drinking and domestic purposes. Water needs to be boiled before used.

Faecal Coliform (FC) (E.coli) is a member of the coliform group which is particularly associated with faecal matter and as such is a good indication of faecal contamination. Faecal coliforms have been shown to represent 93 to 99% of coliform bacteria in faeces from humans, poultry, cats, dogs and rodents (WRC, 2003). Faecal coliforms in boreholes ranged from 0 cfu/mL to 318 cfu/mL. Adding to this FC for surface water was between 900 cfu/mL to 1980 cfu/mL with hand dug wells recording 0 cfu/mL to 1225 cfu/mL. Twelve sites representing 30.8 % fell within the WHO safety limit of 0 cfu/100mL with twenty seven sites representing 69.2 % out of the WHO limit. In this study, Faecal counts of all of the water samples could be attributed to various anthropogenic activities such as to poor sanitation and waste management, defaecation in and around the various surface waters, improper disposal of household waste, improper borehole development technique, location of septic tanks near the boreholes due to lack of space, leaking septic tanks due to improper designs etc. According to van Derslice and Briscoe (1995), in areas with poor environmental sanitation, improved drinking water would have little or no effect. However, in areas with good community sanitation, reducing faecal coliform counts by two orders of magnitude would reduce the incidence of diarrhoea by 40%. These values indicate significant and increasing risk of infectious disease transmission when the water is used for domestic purposes if not properly treated.

Table 0-6: Mean microbiological quality of groundwater sampled from the various communities in the study area.

	Microbial load (cfu/mL)		
Sampling sites	TVC	TC	FC
Abokobi	185	42	2
Dome	562	213	47
Haatso	304	36	1
Kwabenya	264	58	5
Taifa	89	23	4
Pantang	111	43	2

A few general trends could be observed in the data obtained. For example, samples collected from boreholes near the streams and environments with bad sanitation comparatively recorded higher coliforms counts as seen from Table 4.7. This likely resulted from infiltration of coliform-rich surface water through porous soil profiles into the shallow aquifers of the boreholes. Such point sources of coliform-rich water could have been enhanced by the unsanitary conditions that generally prevailed around or close to boreholes (Anim et al., 2010). Water from hand-dug wells and streams also generally has coliform counts higher than borehole (Figures 4 and 5). Again, unlike boreholes, streams and hand-dug wells are more open to contamination from various points and diffuse sources in the surrounding environment. Apart from infiltration of coliform-bearing surficial water, improper constructional design of boreholes at Dome site DB4 which stuck out below the ground levels at the time of sampling likely contributed to the high coliform counts observed in Dome as it collects household waste into the borehole anytime it rains.

Also high coliform counts in boreholes could have been leachates from dumpsites, runoff from poor sanitary environments, poor hygienic conditions, leaky septic tanks etc. Again, behavioural pattern of people in the community using streams as the sink for their household waste by throwing all sort of refuse including human waste into receiving streams (Anim et al., 2010) could also accounts for the high coliform counts. In many communities, such water bodies or areas around them serve as recipients of various forms of domestic and agricultural waste which easily infiltrate the soil and eventually leach out into the streams and rivers (Freeman, 1989). Many hand-dug wells constructed also tap water from shallow aquifers which are highly prone to surficial pollution. As observed in this study, the dumping of refuse and human excreta in and around water bodies is still prevalent (Fig 4.13), suggesting the possibility of contamination from pathogenic bacteria and other sources. Detection of coliforms in borehole water, no matter how low the counts (in cfu/mL), without doubt introduces much concern regarding the bacteriological safety of the water. In some communities, significantly high coliform bacteria in borehole water appear to qualitatively correlate with levels of possible pollution in the immediate surroundings (Anim et al., 2010).

4.5 THE CATIONS

Na^+ correlates positively with Cl^- albeit weakly (Figure 4.9). This could suggest that other processes other than dissolution of halite contribute mainly to the Na^+ ions in groundwater from the study area. The commonest minerals identified in the rocks in the area include plagioclase feldspars, ranging in composition from albite ($NaAlSi_3O_8$) to anorthite ($CaAl_2Si_2SiO_8$), chlorite, illite and muscovite. The Na ions in the groundwater could be as a result of the weathering of albite, yielding the metal Na^+ and silica to solution and forms clay minerals such as illite and montmorillonite. Cation exchange could also contribute to the Na^+ ions in the groundwater. The decomposition of Albite to release Na^+ is represented by equation 4.1.

$$2NaAlSi_3O_3 + 9H_2O + 2H+ \leftrightarrow Al_2Si_2O_5 + 2Na^+ + 4H_4SiO_4 \qquad (4.1)$$

The Cl could be from chlorite.

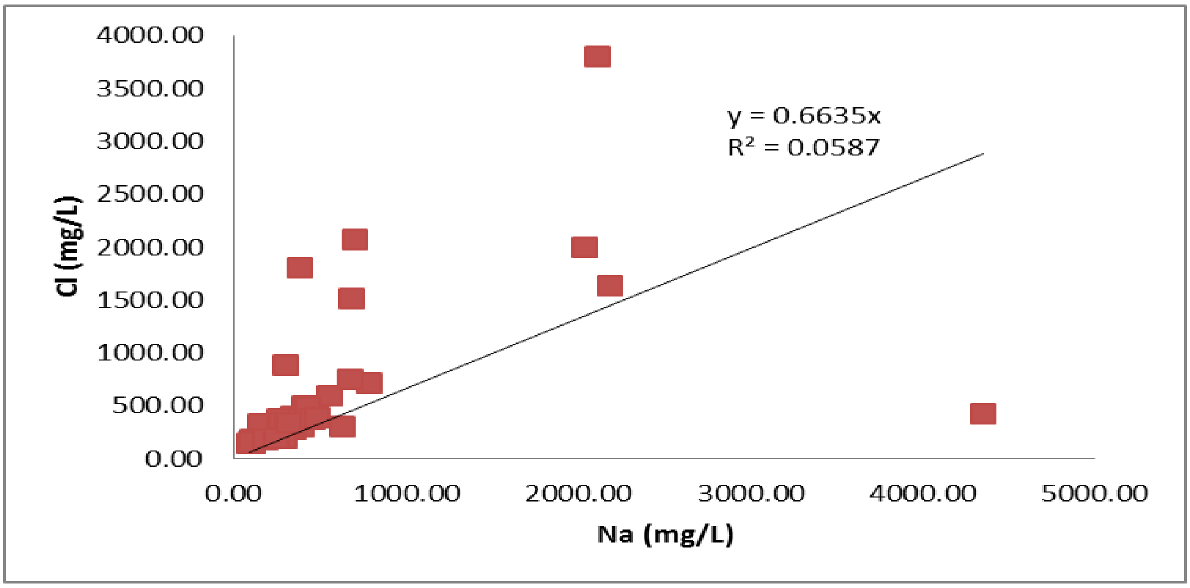

Figure 0-12: A plot of Na^+ against Cl^-

The sodium content of boreholes ranged from 87.3 to 731 mg/L. World Health Organization guideline value for sodium is 200 mg/L. It was observed that thirty one (31) sites representing 73 % have exceeded the permissible limit with only eight sites representing 27% were below the permissible limit for boreholes. For surface water Na^+ concentration ranged from 312mg/L to 452 mg/L with hand dug wells ranging from 315 mg/L to 731 mg/L. All groundwater contains some sodium because most rocks and soils contain sodium compounds from which sodium is easily dissolved and salt water intrusion into wells in coastal areas. This is evident in Figure 4.1 and 4.7 since Na^+ is the dominant cation in the study area. The source of sodium in the groundwater may be from dissolving minerals like silicates, feldspars etc. identified in the rock types of the study area (Chapman, 1992). Infurtherance, human activities such as domestic wastewater as a result of the addition of Table salts to (sodium chloride) food, runoffs from the irrigated farms, sewage effluent from various homes might be source of high concentration of sodium in the study area. Sodium imbalance in drinking water has been reported to cause a large number of life threatening diseases. Hence, the excess consumption of Na^+ has been recognized as risk factor in hypertension (WHO, 1979).

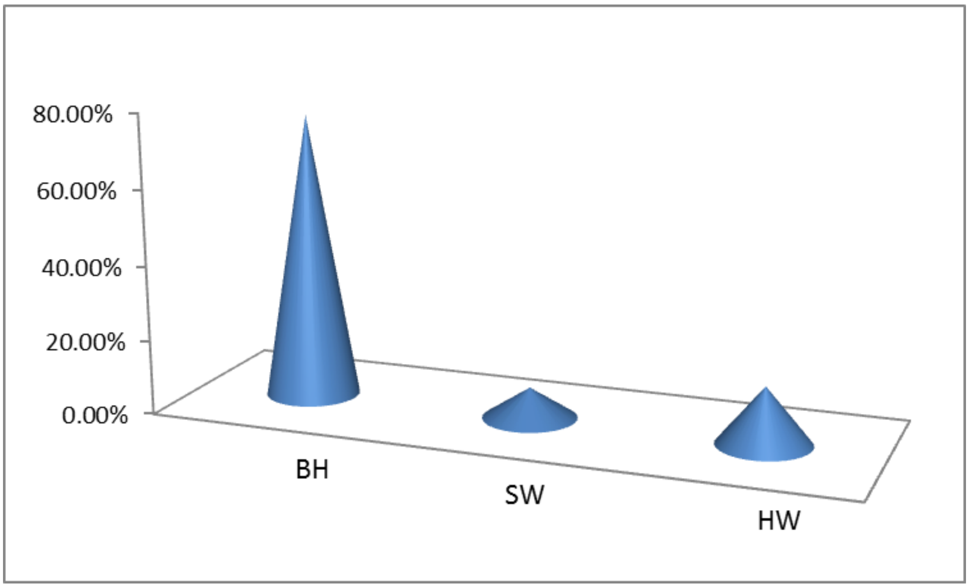

Figure 0-13: Percentages of Sodium composition by water types in the study area

The chemical results from the study area indicate that the Mg^{2+} concentrations generally ranged from 19.92 mg/L to 7.50 mg/L and were all within the WHO, (1996) recommended limit of 150 mg/L as shown in Table 4.1. Surface water recorded magnesium concentration from 16.84 mg/L to 15.87 mg/L with hand dug wells ranging from 11.28 mg/L to 17.85 mg/L.

Although magnesium has been called one of the most important electrolytes in the body and may be connected to lower occurrence of osteoporosis, high concentrations of magnesium can cause diarrhoea and it has a high solubility and is geologically abundant (WRC, 2003). The low concentrations of magnesium as evident in Figure 4.1 in the study area could be as a resulted of dissolution of magnesium from biotite and hornblende (dark amphibole) rocks in the study area.

Potassium is an essential element in humans. It occurs in association with sodium in many minerals in the environment, including all natural waters. Potassium concentration ranged from 3.2 to 502 mg/L with a mean of 42.1 mg/L (Table 4.1) with almost all sites within WHO (1996) (30 mg/L) and WRC (50 mg/L) recommended limit except these six borehole sites namely ABA5 (502 mg/L), DA2 (57 mg/L), HA3 (41 mg/L), PA1 (72 mg/L), TA1(31.2 mg/L), TA2 (31.7 mg/L), three hand dug wells DHA1 (207.30 mg/L), DHA2 (32.8mg/L), PA3 (157 mg/L), and lastly these two surface water HSA1 (47.9 mg/L), HSA2(47.30 mg/L) were found to be above the permissible limit. The high values might have been as a result of rainwater, geological sources and other anthropogenic activities (Chapman, 1992). The geological source of potassium is silicate minerals like orthoclase, microcline, nepheline, Leucite, glauconite and biotite (Fetter, 1994; Knobel and Phillips, 1988; Knobel et al., 1998). In this present study, potassium concentration geologically might be contributed to by potassium feldspars, orthoclase, muscovite etc. which are found in the geological formations of the study area.

Other possible sources of potassium in the water samples might be as a result of runoff from irrigated lands as it is evident in the surface water HSA1 (47.9 mg/L) and HSA2 (47.30 mg/L) receiving potassium from the application of fertilizer in the irrigation farm, sites ABA5 (502 mg/L), DA2 (57 mg/L), HA3 (41 mg/L), PA1 (72 mg/L), TA1(31.2 mg/L), and TA2 (31.7 mg/L), could be having their source of potassium from the Abokobi dumpsite, numerous washing bays in the study area, domestic waste and effluent from septic tanks in various homes that in the boreholes, and the three hand dug wells at DHA1 (207.30 mg/L), DHA2 (32.8 mg/L), and PA3 (157 mg/L) could be having their potassium possibly from domestic waste, leaking septic tanks from homes seeping into groundwater and runoff from the Abokobi dumpsite into PA3.

Increased exposure to potassium could result in significant health effects in people with kidney disease or other conditions, such as heart disease, coronary artery disease, hypertension, diabetes, adrenal insufficiency, pre-existing hyperkalaemia, older individuals who have reduced physiological reserves in their renal function and/or individuals who are taking medications that interfere with the normal handling of potassium in the body (WHO, 2011). On the basis of potassium the groundwater could be used for domestic purpose.

Calcium is an important nutrient for human health but in balanced amount. Calcium is naturally present in water. It may dissolve from rocks such as limestone, marble, calcite, dolomite, gypsum, fluorite apatite and decomposition of sulphate, phosphate and silicate minerals. Calcium is a determinant of water hardness, because it can be found in water as Ca^{2+} ions (APHA 1995).

Calcium is present in various construction materials, such as cement, brick lime and concrete. It is present in batteries, and is applied in plaster as calcium sulphate (WRC, 2003). Groundwater with high calcium content is undesirable for household uses such as washing, bathing and laundering because of consumption of more soap and other cleaning agent (WRC, 2003). Constant use of Calcium rich well water for drinking purposes may lead to kidney stones or gall bladder stones or joint pains in population.

On the individual basis, calcium content ranges from 9.60 mg/L to 379.2 mg/L with mean of 80.4 mg/L having almost all sites within the WHO (200 mg/L) (Table 4.1) permissible limit except only six sites falling out of the limit. Surface water registered calcium concentration of 20.30 mg/L to 22.4 mg/L whilst hand dug wells registered 15.50 mg/L to 249.20 mg/L. Most of these sites are DA1, DA4, DA7 and OPK are in the Dome community with only two sites HA3 and HA4 in the Haatso community signifying a special lithology in the two communities. These lithologies could be calcium–rich plagioclase feldspars and also from the decomposition of anorthite in the study area. Calcium is the second most dominant cation ion in the study area as shown in Figure 4.1.

4.5.1 Trace or heavy metals parameters

Trace or Heavy metals are often referred to as common pollutants which are widely distributed in the environment with sources mainly from the weathering of minerals and soils (Marian, 1991; O’Neil, 1993). The occurrence of trace elements in natural water is affected both by hydro chemical factors like mineral composition of the rocks, soil characteristics etc. as well as by anthropogenic activities and likely to show both temporal and spatial variation.

However the level of these metals in the environment has increased as a result of increase in human activities (Prater, 1975; Marian, 1991).

In any aquifer system, movement and mixing of waters can be expected as hydraulic gradients cause water to move along natural flow paths, such as across confining units or along fracture conduits (Bell et al., 2009). Human-induced gradients, however, are the inevitable result of the use of aquifers for water supply and can enhance trace element mobility by causing water of one geochemical regime to move into another, changing the ambient equilibrium. Differences in pH and redox of the water that moves into an aquifer unit can rapidly mobilize trace elements from the solid phase as mixing progresses (Bell et al., 2009). However, arsenic concentration was found to be below the detected limit in all of the water samples in the study area.

Table 0-7: Trace elements concentrations of water samples in the study area

TRACE ELEMENT PARAMETERS	MINIMUM	MAXIMUM	MEAN	WHO(2011)	WRC(2003)
Fe (mg/L)	< 0.006	3.79	0.25	0.3	0-0.1
Cd (mg/L)	< 0.002	0.019	0.011	0.003	0.05
Zn (mg/L)	< 0.001	0.95	0.062	3	0-3
Pb (mg/L)	< 0.001	0.35	0.051	0.01	0-10
Cr (mg/L)	< 0.001	0.025	0.011	0.05	0-0.05
Cu (mg/L)	< 0.003	0.016	0.009	2.0	0.01
Ni (mg/L)	< 0.001	0.025	0.011	0.07	-
Mn (mg/L)	< 0.002	2.754	0.309	0.04	0-0.05
As (mg/L)	< 0.001	< 0.001	< 0.001	0.01	0.01

Where < 0.006 means below detection limit for Fe

< 0.003 means below the detection limit for Cu

< 0.002 means below detection limit for Mn and cadmium

< 0.001 mean below detection limit for As, Ni, Cr, Zn and Pb

Iron (Fe) and Mn both are essential constituents of plant and animal metabolism. Availability of both iron and manganese in igneous solution is strikingly affected by environmental condition i.e. charge in the degree of oxidation and reduction. Three natural conditions that have been found to produce high levels of iron and manganese in ground water are aquifers located crystalline bed rock, swamps and organic material, interbeded with alluvial sediments located near areas of groundwater discharge (Ramesh, 1999). Iron is also present in the environment due to human activities. Industrial wastes and mine drainage waters are two common anthropogenic sources of iron. Groundwater containing irons at concentration greater than 2 mg/l cause staining of clothes, plumbing fixtures and impart bad taste and colour to water (WHO, 2011).

Normally Fe is only slightly toxic but excessive intake can cause Siderosis and damage to organs through excessive iron storage (Huneey, 2001). Iron in higher concentration may also cause vomiting. Again its deficiency causes anaemia and shortness of breath. The Fe concentrations were within the WHO (2011) 0.3 mg/L which fell within the range of below detection limit to 3.79 mg/L with a mean value of 0.243 mg/L. Fe was below detection limit in five sites namely DC2, KC2, PC1, PC2 and TC4. However four sites namely HC3 (0.434 mg/L), KC5 (1.609 mg/L), KC6 (3.79 mg/L) and HSC2 (0.348 mg/L) were above the WHO limits. But this is not surprising because of the generally high levels of iron in Ghanaian waters (Pelig-Ba et al., 1991). The Fe concentrations may have been dissolution of iron from siderite, hornblende and biotite in the study area.

On the other land, the incidence of Mn toxicity is rare because Mn is rapidly excreted in the kidney. The problem of excess Mn is similar to iron. Manganese is one of the most abundant metals in Earth's crust, usually occurring with iron (WHO, 2011). The Mn concentrations in the ground water of study area had twenty eight sites (71.8%) within the limit of WHO (0.4 mg/L), with three sites (7.7%) having recorded high values above the limits namely ABHC6 (2.754 mg/L), KC5 (0.634mg/L) and KC6 (2.126 mg/L). However, eight sites (20.5%) had Mn below detection limit. At levels exceeding 0.1 mg/l, manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry (WHO, 2001).

Copper is both an essential nutrient and a drinking-water contaminant. Many minerals containing copper is known, some of which are important semi-precious minerals, such as malachite, azurite and turquoise. It has many commercial uses. Copper concentration in the water samples ranged from below detection limit to 0.016 mg/L. Twenty two sites (56.4%) were below detection limit. Seventeen sites (43.6%) had had values below the WHO (2 mg/L). Copper is a very common substance that occurs naturally in the environment and spreads through natural phenomena. Copper enters the air, mainly through release during the combustion of fossil fuels. Copper can be released into the environment by both natural sources such as wind-blown dust, decaying vegetation, forest fires and sea spray and human activities such as are mining, metal production, wood production and phosphate fertilizer production, industrial settings, landfills and waste disposals (APHA 1995).

Water containing amounts higher than 2.00 mg/L is likely to supply too much of this metal. One milligram per litre is also a taste threshold for an average individual. Copper deficiency causes anaemia, loss of hair pigment, growth inhibition and loss of arterial elasticity (APHA

1995). Higher doses of copper can however be very dangerous and toxic to people especially infants resulting in metabolic disorders. In this study, the concentration found in the water samples may be due to leaching of copper from taps, drill bit used in drilling of the boreholes, metal part of the electric pump fitted etc.

Zinc is a metallic element, with the stable oxidation states being the metal (0) and the plus two (+II) oxidation state, which are the forms found in nature. Biologically, zinc is an essential nutritional trace element for plants and animals, but toxic at high concentrations (APHA, 1995). Zinc in the samples ranged from below detection limit to 0.95 mg/l with twenty two sites (56.4%) within the WHO acceptable limit of 3.0mg/L with seventeen sites (43.6%) below detection limit. Zinc salts are used in paint pigment, in cosmetics and in the manufacture of pharmaceuticals, dyes and insecticides. Zinc could be of anthropogenic nature in the water samples from galvanising processes and alloys in the various homes, insecticides products, and paint pigments. Excess Zinc will impart bitter taste and milky appearance to water.

Nickel is used mainly in the production of stainless steel and nickel alloys. Water is generally a minor contributor to the total daily oral intake. However, nickel could be present at areas where there is heavy pollution, areas in which nickel occurs in groundwater naturally; use of certain types of kettles, non-resistant material in wells, water that has come into contact with nickel- plated taps, the nickel contribution from water may be significant (WHO, 2003). In special cases of release from natural or industrial nickel deposits in the ground, the nickel concentrations in drinking water may be higher. Concentration of nickel in the samples ranges from below detection limit to 0.025 mg/L with nineteen (48.7%) samples sites recording values within the WHO guideline limit of 0.07 mg /L and twenty sites (51.3%) below detection limit. Nickel released to the soil may leach into ground water or be washed into surface water. The primary source of nickel in drinking water is leaching from sanitary fixtures. The main threat of nickel contamination comes from the industrial pollution. Excess intake of nickel may be carcinogenic, and can react with DNA resulting in DNA damage, decrease body weight, heart and liver damage, and skin irritation. If it goes to the respiratory tract it increases the risk of lung and nasal cavity cancer (WHO, 2003).

Chromium is widely distributed in Earth's crust. It can exist in valences of +2 to +6. Chromium in drinking water according to WHO and WRC is 0.05 mg/L. Small amount of chromium is essential element being a component of hormone and a vitamin to mammals but in excess it produces harmful effects. The obtained data shows that chromium content in the water samples revealed that 61.5% of the samples were below the detection limit of < 0.001 and 38.5% of samples were all within limits prescribed by the various authorities as shown in Table 4.1. In this study, Chromium could be leached from chromium plated taps, drill bits used in drilling, leaching of chromium plated metals at the Abokobi dump site, disuse dump site at Dome and from paints works in the study areas.

Adding to this, Lead is very toxic element, which accumulates in the skeletal structure of man and animal. The maximum permissible concentration of lead in drinking water is by the WHO (2011) 0.01 mg/L. According to WHO, nineteen sites (49 %) have all the water samples within the WHO safety limit with twenty one sites (51 %) below the detection limit. This might be due to anthropogenic activities such improper disposal of batteries and e-waste at the dump sites, from paints and as lead organic compound (alkyl lead) in gasoline (even though we no more use lead is no more been used in gasoline). Lead taken into the body can be injurious to health. High exposure to lead may cause decreased fertility and ovulatory disturbances and increase malformations and abortions. It may also cause renal and gastrointestinal disturbances. Also, children exposed to lead pollution are under high risk of mental retardation, impaired learning ability, disturbances of peripheral nervous system, and renal atrophy (Khan, 2011).

4.6 THE ANIONS

The chloride content of the water samples ranged from 149.5 mg/L to 3798.82 mg/L with mean 627.91 mg/L as shown by Table 4.1 for boreholes with surface water ranging from 319 mg/L to 379.88 mg/L and with hand dug wells ranging from 189.94 mg/L to 425.87 mg/L. The WHO standard for chloride in drinking water is 250 mg/L and the samples were all above the acceptable limits prescribed by WHO (2011) except nine samples namely: ABA1, ASA4, KA5, KA6, KA7, PA2, and TA2 with values approximately 180 mg/L, 180 mg/L, 160 mg/L, 150 mg/L, 150 mg/L, 160 mg/L, 180 mg/L, 190 mg/L and 200 mg/L respectively. The high levels of the chloride concentration might be due to dissolution of chlorite in the study area. According to Driscoll (1986), there are two sources of chloride in groundwater; sea spray in the form of atmospheric (airborne) salts and dissolution of halite. Once, rainwater falls to the ground, evaporation and transpiration tend to concentrate the Cl^- in soil water to levels ten or more times their original concentrations (Kelly et al., 2012). Rock-water interactions such as mineral dissolution and desorption within the soil zone and groundwater can further increase Cl^- concentrations (Kelly et al., 2012).

Increased Cl^- concentrations in some environments have killed off native vegetation and allowed invasive salt-tolerant species to thrive (Panno et al., 1999). The highest values of chloride are found in sites ABA5 (1640 mg/L) , DA1 (1809 mg/L), DA4 (3799 mg/L), DA7 (2069 mg/L), HA3 (1580 mg/L) and PA1(1999 mg/L) located in the Abokobi near the dumpsite, DA1 in Dome near an old disuse refuse dump which has a house on it may be leaching chloride into nearby boreholes , DA4 and DA7 all in Dome have a technical design of the borehole poorly constructed with the stick out below the ground surface which collects waste water into it making it full anytime it rains, for site HA3 might be due to runoff from the irrigation sites at the Haatso vicinity and lastly PA1 might also be as a result of leachate from the dumpsite. The chloride at higher concentration can damage metallic pipes and structures and hampers agricultural crops.

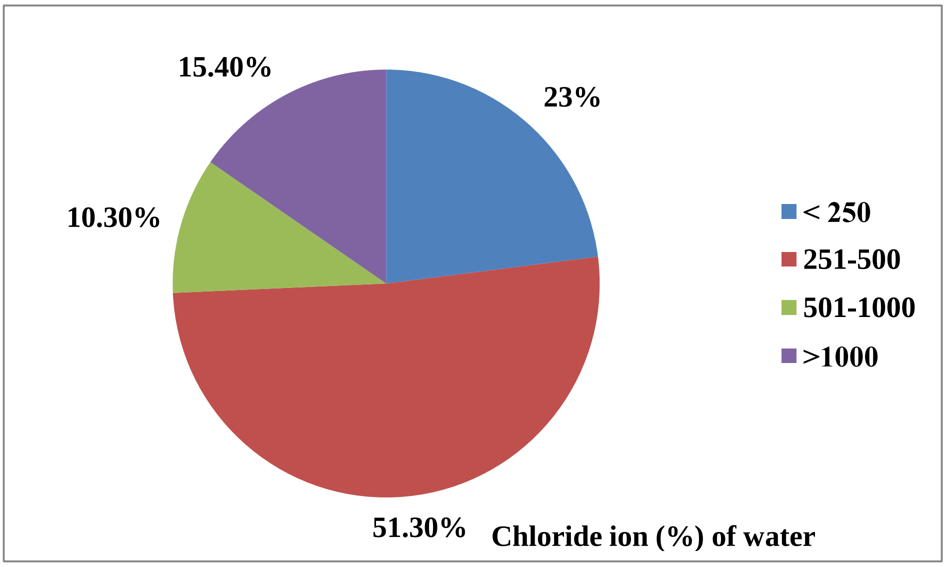

Figure 0-14: Pie-Chart showing the percentage distribution of chloride ion in water samples from the study area

The rocks in which most of the Phosphorus is bound, are generally insoluble and hence phosphate concentration in the freshwater is generally less than 1 ppm (Nikumbh et al., 1997). The phosphate content of the samples ranged from < 0.001 (below detection limit) to 0.924 mg/L with all being within the WHO acceptable limit of 250 mg/L. If phosphate is consumed in excess, phosphate gas is produced in gastro–intestinal tract on reaction with gastric juice causing interference with digestion in both humans and animals (Bheshdadia et al., 2011).

Sulphate appears in natural water in wide range of concentrations, usually between 2 mg/L and 80 mg/L though they may exceed 1000 mg/L near industrial discharges or in arid regions where sulphate minerals such as gypsum and anhydrites are present (Chapman, 1992). In water it may be derived from the atmospheric deposition of oceanic aerosols or the oxidation of sulphide bearing minerals such as pyrite and arsenopyrite (Chapman, 1992). The sulphate levels of the water samples ranged from 7.10 mg/L to 382.26 mg/L with mean 95.73 mg/L and were within the WHO limit of 200 mg/L except sites ABA5 (358.57 mg/L) which is a borehole near the Abokobi dumpsite, DA4 (382.26 mg/L) is a borehole that was improperly constructed with the stick out below the land surface collecting runoff into it anytime it rain, PA3 (355.12 mg/L) water collected from a shallow well few meters to the downside of Abokobi dumpsite and TA1 (212.42) borehole in Taifa community near a washing bay were above the WHO and WRC limits. In the study area, sulphate is the third most dominant anion with seven percent (7%) for boreholes and ten percent (10%) for hand dug wells. The major source of sulphate in the groundwater is rainwater, sulphur minerals and sulphides of heavy metals are from igneous and metamorphic rocks (Hem, 1991). Gypsum, anhydride from sedimentary rocks, soil amendments fertilizers and burning of fossil fuel are also important sources of sulphate (Hem, 1991). If sulphate in groundwater exceeds the limit, a bitter medicinal taste may render the water unpleasant to drink and causes diarrhoea and dehydration (WHO, 2011). The major physiological effect resulting from the ingestion of large quantities of sulphate leads to catharsis, dehydration, and gastrointestinal irritation (WHO, 2011).

Nitrate concentrations ranged from < 0.001 (below detection limit) to 1.97 mg/L (Table 4.1) were within the acceptable limit prescribed by WHO (2011) (50 mg/L). Human and animal wastes, industrial effluents, application of agro chemicals, seepage and silage through drainage system are the main sources of nitrate. Excessive nitrate content in drinking water can cause health disorders such as methaemoglobinaemia ("blue-baby syndrome") goitre, and hypertension (Baird and Cann, 2004). Additional consequences among people who consumed drinking water containing high level of nitrate is enlargement of the thyroid gland, increased incidence of 15 types of cancer and two types of birth defects and even hypertension were reported (Forman et al 1985). This suggests no immediate threat to the health of infants in the community from nitrate pollution.

Fluorine is a common element that is widely distributed in Earth's crust and exists in the form of fluorides in a number of minerals, such as fluorspar, cryolite and fluorapatite and sometimes from the use of phosphate fertilizers (which contain 4% fluorine). Traces of fluorides are present in many waters, with higher concentrations often associated with ground waters (WHO, 2011). Fluoride is essential for good oral health and serves to guard against tooth decay. The WHO (2011) recommended value for fluoride in drinking water is 1.5 mg/L. The fluoride concentrations were within normal limits (Table 4.1) except eight sites namely ABA4 (2.04 mg/L), DA1 (2.09 mg/L), DA2 (1.75 mg/L), DA7 (1.99 mg/L), HA1 (1.66 mg/L), KA1 (2.06 mg/L), PA1 (1.95 mg/L) and KHA1 (1.88 mg/L) which had levels above the WHO (1.5 mg/L).

The high fluoride concentrations may have been due to weathering of fluoride-containing minerals rocks through direct contact in the study area. Fluoride is frequently found in certain industrial processes and consequently in resulting wastewaters (APHA, 1995). The use of these waters for a long time could cause mottling of the teeth called fluorosis. It could also lead to brittle teeth and in extreme cases even skeletal fluorosis (WHO, 2011).

Dissanayaka, (1991) and Apambire et al., (1997) summarized the likely impacts from long-term consumption of fluoride-bearing water water as:

< 0.5 mg/L: dental caries

0.5 to 1.5 mg/L: promotes dental health

1.5 to 4 mg/L: dental fluorosis

> 4 mg/L: dental and skeletal fluorosis

> 10 mg/L: crippling skeletal fluorosis

In the study area, however, thirteen (13) samples representing 33 % fall within < 0.5 mg/L with eighteen(18) samples representing 46 % fall within 0.5 to 1.5 mg/L and lastly eight samples representing 21 % fall within 1.5 to 4 mg/L. There may therefore be the likelihood of the risk of dental fluorosis, suffered by people who depend on these water sources that were within 1.5 mg/L to 4 mg/L for drinking in the study area.

Bicarbonate (HCO_3^-) concentrations in natural waters are as a result of dissociation of $H_2CO_3^-$ (Chapelle et al., 1987). Davis et al. (1966) observed that most bicarbonate ion in groundwater is derived from carbon dioxide in the atmosphere, CO_2 in the soil zones and dissolution of carbonate rocks. Weathering of silicate minerals also acts as an important CO_2 sink (Appelo and Postma, 2005). Thus, water in contact with carbon dioxide produces bicarbonate ion and acid (Equation 4.2).

$$CO_2 + H_2O \Leftrightarrow H^+ + (HCO_3^-) \qquad (4.2)$$

Also, carbonate and bicarbonates may originate from the microbial decomposition of organic matter (Jain et al., 1997). High bicarbonate levels in groundwater can cause stunted growth in plants which can subsequently lead to calcite precipitation, decreasing soil permeability, lowering infiltration capacity and increasing erosion (McLean and Jankowiski, 2000). In the present study, bicarbonate of boreholes was in the range 300mg/L to 1100 mg/L with a mean of 701.49 mg/L (Table 4.1). For surface water HCO_3^- was found to be 700mg/L to 1000 mg/L with Hand dug wells registering 8 mg/L to 2000 mg/L.

All samples in the study area were found to be outside the WHO (1996) limits of 380 mg/L except only two sites PA3 (8 mg/L) and ABA3 (300 mg/L). Bicarbonate ion concentration in groundwater could be derived from areas underlain by rocks composed of potassium feldspar, plagioclase feldspar or quartz (Appelo and Postma, 1996). The bicarbonate concentration observed in the study area might be due to the weathering of underlain rocks composed of potassium feldspar, plagioclase feldspar or quartz which make up the geologic formation of the study area.

4.7 SUITABILITY FOR IRRIGATION USE

The suitability of groundwater for agricultural irrigation was assessed using the Sodium Adsorption Ratio (SAR). SAR is important to plant growth because its magnitude is an indication of the availability of soil pore water to plant roots (Weiner, 2000). The higher the SAR, the less suitable the water is for irrigation. Irrigation water with excess sodium can affect soil structure, soil aeration, flow rate, permeability, infiltration etc. The SAR calculated for all groundwater samples in the district ranged from 5 to 25 with a mean of 14.5 (Appendix A2). According to Richards (1954) classification based on SAR values, all samples were evenly distributed but could be placed in the Good to doubtful category and (Table 4.17) implying that groundwater in the district could be used for irrigation. This is true, provided essential nutrients like nitrogen and available phosphorus are not limiting in soils in the district.

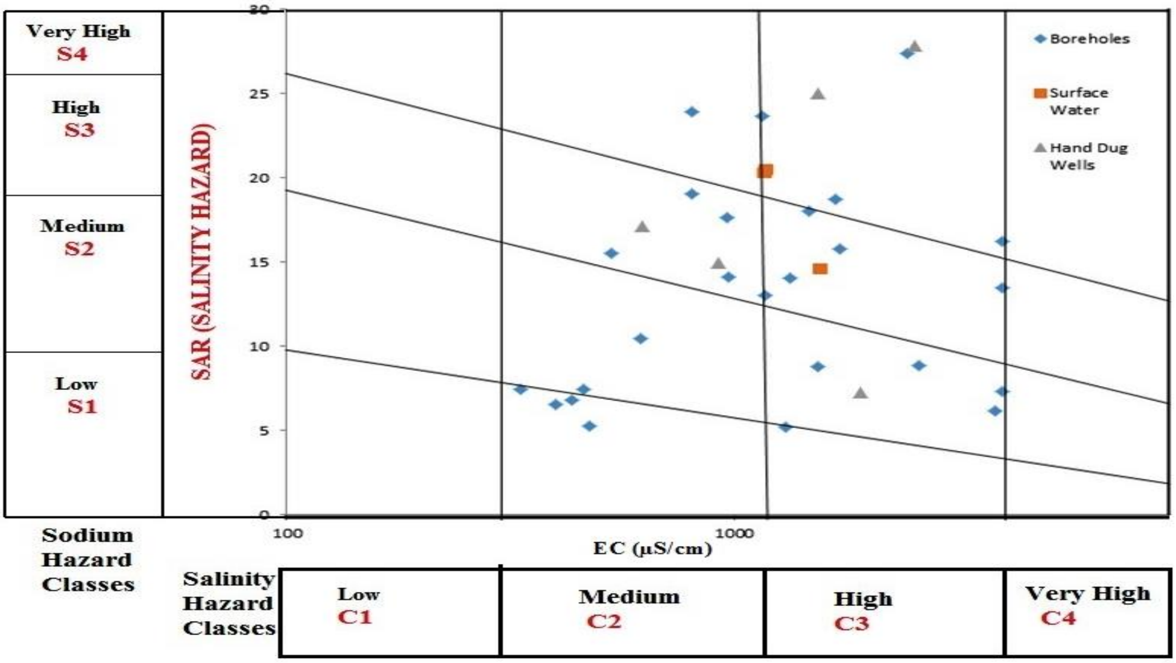

Figure 0-15: Salinity diagram of groundwater samples from the study area

Table 0-8: Classification of water samples based on salinity hazard

Salinity Hazard	EC(µS/cm)	Water Class	Number of samples
C1	100-250	Excellent	Nil
C2	250-750	Good	13
C3	750-2250	Doughtful	19
C4	>2250	Unsuitable	Nil

Table 0-9: which is classification based on USSL sodium hazard for irrigation.

Sodium	EC(µS/cm)	Water Class	Number of samples
S1	< 10	Excellent	5
S2	10-18	Good	7
S3	18-26	Doughtful	12
S4	>26	Unsuitable	8

4.8 HUMAN HEALTH RISK ASSESSMENT

4.8.1 Hazard Quotient (HQ)

Hazard Quotient (HQ) of water samples was assessed by the ratio of daily intake (DI) to the oral reference dose (R_fDo) for each metal (USEPA 2013). In this present study, HQ for all water samples was generally low and was less than one as seen in Table 4.12.

Table 0-10: Percentage HQ of water sample in the study area for adults and children

Heavy Metal	Below Detection Limit (%)		HQ <1(%)		HQ >1(%)	
	Adults	Children	Adults	Children	Adults	Children
Fe	15	15	85	85	0	0
Cd	92	90	5	3	3	7
Zn	46	46	54	54	0	0
Pb	53	54	44	28	3	18
Cr	62	62	38	38	0	0
Cu	56	56	44	44	0	0
Ni	51	51	49	49	0	0
Mn	21	21	79	74	0	5
As	100	100	0	0	0	0

The high HQ for Pb Cd and Mn observed had greatest potential to pose health risk to the consumers of these water samples from the various sample sites as seen in Table 4.11. In the affected areas that is KA5,KA9,ABA4,ABA1,HA3KA3,KBA1,DHA1,DHA2,PA3 and HSA1 HQ was equal or greater than one (= or > 1) meaning it poses a health risk to consumers of these water sample. It was revealed that children mostly stand the risk of health problem associated with the consumption of these heavy metals in the water samples.

Table 0-11: Risk prone water samples sites in the study area.

Trace (Heavy) Element	Hazard Quotient			
	Adult	Children		
		BH	HDW	SW
Fe	-	-		
Cd	KA5(1.3 E-00)	ABA4(2.6E-00) KA5(3.8 E-00)		PA3(1.6 E-00)
Zn	-	-		
Pb	KA9(2.9)	ABA1(1.9E-00) HA3(1.1E-00) KA3(8.7 E-00), KBA1(1.3 E-00)	DHA1(1.8 E-00) DHA2(2.3 E-00)	HSA1(2.1 E-00)
Cr	-	-		
Cu	-	-		
Ni	-	-		
Mn	-	KA4(1.5 E-00),	ABHA6(1.9 E-00)	

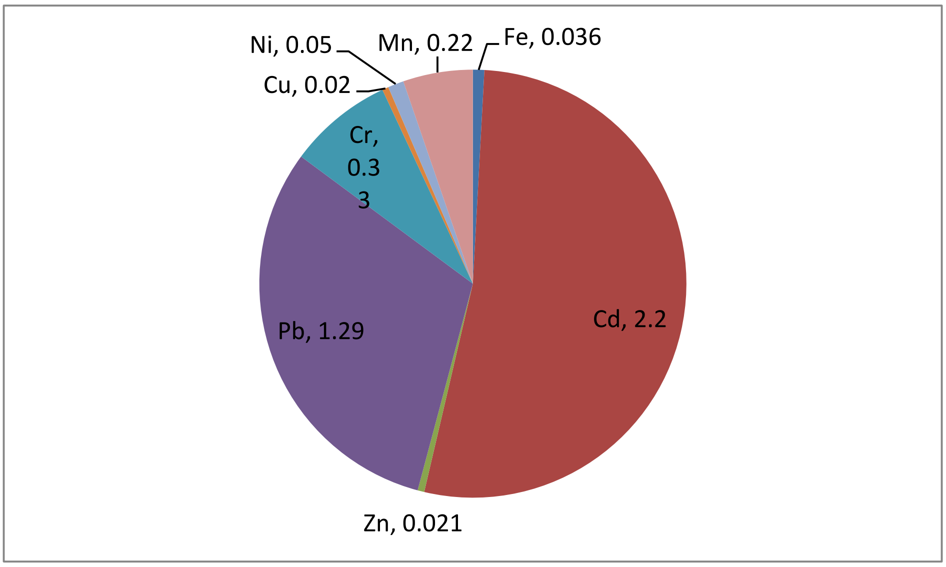

Figure 0-16: Mean HQ for children in the study area from one sample site

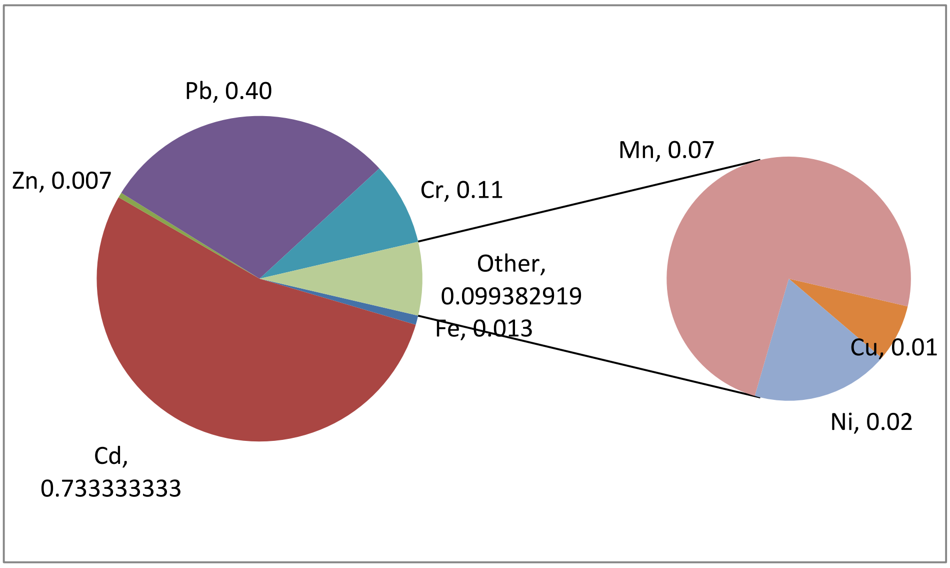

Figure 0-17: Mean HQ for Adults in the study area from one sample site

4.8.2 Hazardous Index (HI)

The hazard index is the sum of the hazard quotients for all heavy metals, which was calculated by the Eqn. (Guerra et al., 2010).

$HI = \Sigma HQ = HQ_{Cd} + HQ_{Fe} + HQ_{Zn} + HQ_{Pb} + HQ_{Cr} + HQ_{Cu} + HQ_{Ni} + HQ_{Mn}$ --- Eqn (5)

Also,38.5% of the sample has HI equal or greater than one(= or >1) indicating that there is a relative health risks associated with the ingestion of these samples as seen in Table 4.13a and 4.13b . Children here again are at somewhat higher risk than adults. If one sampling site recorded all the trace element present in the water, their sum is calculated if equal or greater than one then it pose a high risk of health problems to the consumer of such water.

Table 0-12(a): Hazard Index for Adult

WT	S. ID	HI
BH	ABA1	0.75345
BH	ABA2	0.0474
BH	ABA3	0.0827
BH	AB4	1.0165
BH	ABA5	0.0925
BH	ASA4	0.0466
BH	DA1	0.0677
BH	DA2	0.3872
BH	DA3	0.1732
BH	DA4	0.4483
BH	DA7	0.2308
BH	DA8	0.0247
BH	DA9	0.0471
BH	HA1	0.1101
BH	HA2	0.0031
BH	HA3	0.5370
BH	HA4	0.1278
BH	KA1	0.1556
BH	KA2	0.4346
BH	KA3	2.9950
BH	KA4	0.8478
BH	KA5	1.6053
BH	KA6	0.0016
BH	KBA1	0.6855
BH	PA1	0.0342
BH	PA2	0.0046
BH	PA3	0.7279
BH	TA1	0.0317
BH	TA2	0.0075
BH	TA3	0.0695
BH	TA4	0.0158
SW	ABHA6	0.7426
SW	HSA1	1.0278
SW	HSA2	0.0644
HDW	DHA1	0.7674
HDW	DHA2	1.0057
HDW	KHA2	0.0021
HDW	THA1	0.0145
HDW	OPK	0.2308

Table 0-13 (b): Hazard Index for Children

WT	S. ID	HI
BH	ABA1	2.2554
BH	ABA2	0.1423
BH	ABA3	0.2480
BH	AB4	3.0494
BH	ABA5	0.2775
BH	ASA4	0.1399
BH	DA1	0.203
BH	DA2	1.1617
BH	DA3	0.5197
BH	DA4	1.3449
BH	DA7	0.6922
BH	DA8	0.0731
BH	DA9	0.1413
BH	HA1	0.3301
BH	HA2	0.0094
BH	HA3	1.6109
BH	HA4	0.3833
BH	KA1	0.4668
BH	KA2	1.3037
BH	KA3	8.9851
BH	KA4	2.5434
BH	KA5	4.8160
BH	KA6	0.0047
BH	KBA1	2.0565
BH	PA1	0.1027
BH	PA2	0.0137
BH	PA3	2.1838
BH	TA1	0.095
BH	TA2	0.0226
BH	TA3	0.2086
BH	TA4	0.0475
SW	ABHA6	2.2277
SW	HSA1	3.0834
SW	HSA2	0.1933
HDW	DHA1	2.3022
HDW	DHA2	3.0170
HDW	KHA2	0.0063
HDW	THA1	0.0434
HDW	OPK	0.6922

4.9 SOME POSSIBLE ANTHROPOGENIC SOURCES OF GROUNDWATER CONTAMINATION IN THE STUDY AREA

Human activities that might be compromising the groundwater quality in the Municipality as observed are improper disposal of waste, drilling boreholes near crack septic tanks as a results of limited or scarce land, effluents from soak aways , runoff from humans and animals waste in the various communities.

Adding to this, bad drilling techniques such stick outs are below the ground surface which collects waste water into boreholes anytime it rains, poor sanitation conditions in the Municipality, leachate from the Abokobi dump site and disuse dump site at Dome and other ones in the Municipality, runoff from most irrigation sites in the Municipality especially Haatso irrigation sites, improper disposal of batteries and e-waste and discharges from small scale industries such washing bays , mechanic shops etc as in the Figure 4.18

Figure 0-18: Some human activities that might impact on groundwater quality in the study area

CHAPTER FIVE

CONCLUSIONS AND RECCOMENDATIONS

5.1 CONCLUSIONS

The research has shown that groundwater quality in the study area is compromised by geogenic and anthropogenic sources. The study revealed also the source of ion in the waters of the study area as mainly mineral weathering.

The result of waters in the study area shows that the pH (4.35 to 8.97) is slightly acidic and slightly alkaline but most samples were within the WHO guidelines for domestic uses.

Three different water types were identified in the study area. These waters are Na-Cl, Na-HCO_3 and HCO_3-Cl water types.

Bacteriologically, most of the water samples are contaminated with Total Coliform and E. Coli resulting from human activities. The study also revealed that surface water gets contaminated easily with Total Coliform Counts Bacteria and E. Coli followed by hand dug wells and boreholes (if not properly constructed).

The human health risk assessment has shown that children stand the high risk of health related problems as a result of taking in contaminated water with heavy metals (Pb, Cd and Mn) as seen from sites ABA4 (2.6E-00), KA5 (3.8 E-00), ABA1 (1.9E-00), HA3 (1.1E-00), KA3 (8.7 E-00), KBA1 (1.3 E-00), DHA1 (1.8 E-00), DHA2 (2.3 E-00), KA4 (1.5 E-00), ABHA6 (1.9 E-00).

Generally, the waters could be used for other domestic purposes except for drinking.

5.2 RECCOMENDATION

Some people in the Municipality rely on the groundwater as their main source of drinking water and also for other socio-economic activities, it is required that appropriate measures are put in place to safeguard the source of water and its sustainability and the health of the inhabitants, this research therefore recommends the following measures to be taken;

1. Waters in the boreholes with high heavy metal contents should be treated before drinking in order to eliminates any negative effects on the health of consumers.
2. In case treatment facilities are not available ,then the waters could be used for other domestic purposes other than for cooking and drinking.
3. Feasibility studies for borehole sitting should be conducted prior to drilling.
4. Water quality analysis be carried out on all the boreholes in the Municipality at least once every two years. This will ensure that incidences of contamination are noticed earlier for remedial action to be taken.
5. Periodic health check by borehole owners and all users of such water is highly recommended.
6. Human health risk assessment be carried out on all newly constructed boreholes in the Municipality and existing ones at least once every two years.
7. “Well-pooling”, is practiced to better protect groundwater resources through the efficient management of boreholes.
8. Water should be boiled before drinking to kill most of the pathogens in the water.

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APPPENDIX

APPENDIX A Physico-chemical parameters results in the Ga East District

SAMPLE ID	Type	pH	Temp.	EC	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}
ABA1	BH	5.77	27.60	1542	766	141.00	14.10	14.40	1.198
ABA2	BH	5.06	28.50	976	486	237.00	16.90	16.00	1.323
ABA3	BH	5.83	29.10	808	403	344.00	10.20	20.80	1.426
ABA4	BH	6.88	28.70	1304	650	158.00	10.30	105.60	1.617
ABA5	BH	6.63	29.20	3999	2000	2186.00	502.00	171.20	1.763
ASA4	BH	5.70	28.70	460	227	109.70	8.10	9.60	1.173
DA1	BH	7.08	29.10	3999	2000	384.00	25.90	379.20	1.851
DA2	BH	5.71	29.60	2448	1221	782.00	57.00	43.20	1.55
DA3	BH	6.25	29.90	1473	737	409.00	19.20	46.40	1.574
DA4	BH	7.18	29.70	3999	2000	2106.00	20.40	320.00	1.992
DA7	BH	6.98	34.50	3999	2000	701.00	23.70	246.40	1.785
DA8	BH	5.88	29.90	1176	580	264.00	19.20	32.00	1.497
DA9	BH	5.74	29.90	534	268	345.00	23.60	46.40	1.419
HA1	BH	6.66	28.70	2445	1220	560.00	20.70	35.20	1.403
HA2	BH	5.60	29.50	1692	841	394.00	25.20	35.20	1.589
HA3	BH	6.58	29.80	3999	2000	683.00	41.00	355.20	1.741
HA4	BH	6.80	28.80	3837	1919	310.00	10.10	350.20	1.738
KA1	BH	6.66	28.70	2445	1220	677.00	3.20	24.00	1.691
KA2	BH	7.16	28.70	1338	669	277.00	9.20	24.00	1.721
KA3	BH	4.96	28.30	805	405	347.00	8.70	9.60	1.12
KA5	BH	4.35	29.70	435	217	109.60	13.00	12.80	1.33
KA6	BH	5.86	28.20	401	200	108.40	8.90	12.80	1.416
KA7	BH	5.95	28.50	475	240	87.30	5.10	12.80	1.444
KBA1	BH	6.96	28.90	969	486	333.00	12.80	20.80	1.654
PA1	BH	5.33	29.70	3999	2000	2034.00	72.00	123.20	1.739
PA2	BH	5.55	29.20	334	166	95.20	16.10	9.60	0.76
TA1	BH	4.91	30.70	1155	575	381.00	31.20	12.80	1.33
TA2	BH	5.37	29.60	621	309	179.00	31.70	19.20	1.272
TA3	BH	6.78	30.00	2588	1290	300.00	16.40	137.60	1.77
TA4	BH	6.91	29.40	1726	860	432.00	19.10	80.00	1.684
ABHA6	SW	6.88	27.30	1568	782	453.00	25.10	22.40	1.587
HSA1	SW	8.40	32.80	1185	593	315.00	47.90	3.60	1.62
HSA2	SW	8.50	33.30	1178	637	312.00	47.30	3.20	1.632
PA3	HDW	8.97	28.90	3999	2000	4352.00	157.00	20.80	1.99
DHA1	HDW	7.17	28.80	2544	1256	627.00	207.00	46.10	1.556
DHA2	HDW	7.00	29.20	920	460	291.00	32.80	32.00	1.286
KHA1	HDW	7.16	28.70	1542	766	483.00	12.00	24.00	1.649
THA1	HDW	5.17	28.80	622	312	244.00	6.80	8.00	1.128
OPK	HDW	7.53	28.40	1913	952	315.00	11.21	249.20	1.785

Appendix A Physico chemical parameters results (continued)

SAMPLE ID	**Cl**	F^-	HCO_3^-	SO_4^{2-}	NO_3^-	PO_4^{2-}	**Sal.**	**TH**	**TSS**
ABA1	179.94	0.33	500	39.839	0.782	0.005	1.60	600	0
ABA2	309.90	0.18	700	45.323	< 0.001	0.067	2.60	1000	0
ABA3	399.88	0.08	300	34.355	< 0.001	0.005	3.20	1100	0
ABA4	329.90	2.04	900	99.516	0.841	0.018	4.00	800	0
ABA5	1639.49	0.42	900	358.548	1.965	0.139	14.80	2200	32
ASA4	179.94	0.18	600	72.581	0.082	< 0.001	1.50	600	0
DA1	1809.44	2.09	950	40.806	0.906	0.005	13.20	2400	0
DA2	719.78	1.75	400	102.483	0.688	0.030	71.00	1200	0
DA3	499.85	0.11	400	65.161	0.459	0.031	4.40	800	0
DA4	3798.82	1.40	400	382.258	< 0.001	0.005	22.80	6000	1
DA7	2069.36	1.99	700	190.968	0.771	< 0.001	13.30	3400	0
DA8	379.88	0.53	500	7.097	<0.001	< 0.001	3.60	5500	0
DA9	319.90	0.27	500	16.290	< 0.001	< 0.001	3.80	600	0
HA1	599.81	1.66	800	22.581	1.841	< 0.001	5.10	800	0
HA2	299.91	1.00	900	96.774	< 0.001	0.418	4.50	800	1
HA3	1519.53	0.64	900	114.516	< 0.001	0.007	12.00	2700	0
HA4	341.99	0.82	750	62.350	0.716	0.018	4.10	1215	0
KA1	749.77	0.72	700	64.032	1.000	0.003	6.90	1400	0
KA2	339.89	0.80	900	89.194	0.706	0.010	41.00	1200	0
KA3	279.91	1.20	1000	132.581	1.352	0.007	2.70	800	0
KA5	159.95	0.21	600	37.742	0.512	0.003	1.60	700	0
KA6	149.95	0.10	600	59.355	0.118	< 0.001	1.50	200	6
KA7	149.95	0.80	400	69.677	0.029	0.405	1.30	800	57
KBA1	309.90	2.06	1000	54.677	0.618	0.010	3.70	1100	0
PA1	1999.38	1.95	500	62.742	1.165	< 0.001	14.70	1400	0
PA2	159.94	0.48	600	49.517	1.841	< 0.001	1.20	600	0
TA1	379.88	0.21	400	212.420	1.471	0.013	3.70	400	0
TA2	179.94	0.41	400	45.480	1.088	0.008	2.10	400	0
TA3	879.73	0.44	1100	40.968	0.871	< 0.001	7.60	1800	0
TA4	479.85	1.11	600	71.129	1.041	0.010	5.20	1600	0
ABHA6	379.88	1.03	700	146.129	0.965	0.065	4.80	700	0
HSA1	322.00	1.00	900	47.332	1.098	0.129	4.40	700	6
HSA2	319.90	1.00	1000	48.226	1.088	0.124	4.10	600	5
PA3	425.87	0.89	8	355.120	10.000	0.924	8.00	220	7
DHA1	299.91	1.21	900	157.091	0.876	0.155	7.10	1600	0
DHA2	189.94	1.12	500	58.226	0.029	< 0.001	2.80	600	0
KHA1	389.88	1.88	2000	90.806	0.906	0.021	5.00	800	0
THA1	199.94	0.18	700	24.194	0.776	< 0.001	2.10	1500	0
OPK	345.99	0.85	750	65.480	0.023	0.023	4.20	1218	0

Appendix A; Physico chemical parameters results (continued)

Sample ID	Fe	Cd	Zn	Pb	Cr	Cu	Ni	Mn	As
ABA1	0.061	< 0.002	< 0.001	0.08	0.01	0.01	0.01	< 0.002	< 0.001
ABA2	0.002	< 0.002	< 0.001	< 0.001	< 0.001	0.01	0.02	0.07	< 0.001
ABA3	0.060	< 0.002	0.008	ND	< 0.001	0.01	0.03	0.14	< 0.001
AB4	0.129	0.013	0.005	0.01	< 0.001	< 0.003	0.01	0.25	< 0.001
ABA5	0.204	< 0.002	0.010	0.01	< 0.001	< 0.003	0.00	0.04	< 0.001
ASA4	0.038	< 0.002	0.009	< 0.001	< 0.001	< 0.003	0.01	0.09	< 0.001
DA1	0.046	< 0.002	< 0.001	< 0.001	< 0.001	< 0.003	0.01	0.21	< 0.001
DA2	< 0.006	< 0.002	0.010	0.01	0.02	0.02	0.01	0.26	< 0.001
DA3	0.031	< 0.002	0.013	0.01	0.01	0.01	< 0.001	0.10	< 0.001
DA4	0.046	< 0.002	< 0.001	0.04	0.01	0.01	0.01	0.01	< 0.001
DA7	0.024	< 0.002	< 0.001	0.01	0.01	0.01	< 0.001	0.35	< 0.001
DA8	0.080	< 0.002	0.005	< 0.001	< 0.001	< 0.003	0.01	0.05	< 0.001
DA9	0.030	< 0.002	0.006	< 0.001	< 0.001	< 0.003	0.02	0.06	< 0.001
HA1	0.114	< 0.002	0.003	0.01	< 0.001	< 0.003	< 0.001	0.05	< 0.001
HA2	0.066	< 0.002	< 0.001	< 0.001	< 0.001	< 0.003	< 0.001	< 0.002	< 0.001
HA3	0.434	< 0.002	< 0.001	0.05	0.01	0.01	0.00	0.13	< 0.001
HA4	0.238	< 0.002	< 0.001	< 0.001	< 0.001	< 0.003	0.02	0.35	< 0.001
KA1	0.045	< 0.002	0.006	< 0.001	0.01	0.01	< 0.001	< 0.002	< 0.001
KA2	< 0.002	0.004	0.011	0.02	0.00	< 0.003	< 0.001	< 0.002	< 0.001
KA3	< 0.002	< 0.002	0.012	0.35	0.01	0.01	< 0.001	0.03	< 0.001
KA5	1.609	< 0.002	< 0.001	0.03	< 0.001	0.01	0.01	2.13	< 0.001
KA6	3.790	0.019	0.065	< 0.001	< 0.001	< 0.003	< 0.001	0.63	< 0.001
KA7	0.026	< 0.002	0.003	< 0.001	< 0.001	< 0.003	< 0.001	< 0.002	< 0.001
KBA1	0.026	< 0.002	0.014	0.05	0.01	0.01	0.01	0.23	< 0.001
PA1	< 0.002	< 0.002	0.083	< 0.001	< 0.001	< 0.003	< 0.001	0.11	< 0.001
PA2	< 0.002	< 0.002	0.041	< 0.001	< 0.001	< 0.003	< 0.001	< 0.002	< 0.001
TA1	0.010	< 0.002	< 0.001	< 0.001	< 0.001	< 0.003	< 0.001	0.13	< 0.001
TA2	0.029	< 0.002	0.004	< 0.001	< 0.001	< 0.003	< 0.001	0.02	< 0.001
TA3	0.080	< 0.002	0.015	< 0.001	< 0.001	< 0.003	< 0.001	0.27	< 0.001
TA4	< 0.002	< 0.002	0.029	< 0.001	< 0.001	< 0.003	< 0.001	0.05	< 0.001
ABHA6	0.074	< 0.002	< 0.001	0.01	< 0.001	< 0.003	< 0.001	2.75	< 0.001
HSA1	0.078	< 0.002	< 0.001	0.09	0.03	0.02	0.01	0.07	< 0.001
HSA2	0.348	< 0.002	< 0.001	< 0.001	< 0.001	< 0.003	ND	0.20	< 0.001
PA3	0.281	0.008	0.950	< 0.001	0.00	0.01	0.02	0.02	< 0.001
DHA2	0.026	< 0.002	< 0.001	0.09	0.02	0.01	0.01	< 0.002	< 0.001
KHA1	0.044	< 0.002	< 0.001	< 0.001	< 0.001	< 0.003	< 0.001	< 0.002	< 0.001
THA1	0.039	< 0.002	< 0.001	< 0.001	< 0.001	< 0.003	< 0.001	0.05	< 0.001
OPK	0.024	< 0.002	< 0.001	0.01	0.01	0.01	< 0.001	0.35	< 0.001

SAMPLE ID	Type	TVC	TC	FC
ABB1	BH	311	38	5
ABB2	BH	215	98	0
ABB3	BH	58	58	0
ABB4	BH	25	0	0
ABB5	BH	300	32	6
ASB4	BH	201	26	1
DB1	BH	390	25	2
DB2	BH	250	69	3
DB3	BH	95	35	0
DB4	BH	2980	1225	318
DB7	BH	55	33	0
DB8	BH	45	49	0
DB9	BH	121	55	3
HB1	BH	311	25	2
HB2	BH	280	37	0
HB3	BH	336	25	1
HB4	BH	290	55	0
KB1	BH	120	15	1
KB2	BH	39	9	0
KB3	BH	68	17	0
KB5	BH	78	15	1
KB6	BH	200	22	3
KB7	BH	1200	290	25
KBB1	BH	145	39	2
PB1	BH	186	35	5
PB2	BH	35	11	2
TB1	BH	120	68	2
TB2	BH	95	55	0
TB3	BH	75	24	3
TB4	BH	65	23	1
ABHB6	SW	4130	2510	1980
HSB1	SW	5010	3600	1350
HSB2	SW	2900	1510	900
PB3	HDW	3500	2001	1225
DHB1	HDW	2110	760	110
DHB2	HDW	490	190	125
KHB	HDW	540	230	29
THB1	HDW	550	155	56
OPK	HDW	30	0	0