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HYDROGEOCHEMICAL ANALYSIS OF GROUNDWATER IN THE SAWLA-TUNA-KALBA DISTRICT OF THE NORTHERN REGION OF GHANA

BY

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THIS DISSERTATION IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MSC GROUNDWATER RESOURCE DEVELOPMENT DEGREE

MAY, 2013

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DECLARATION

I do hereby declare that with the exception of references to other authors' work, which have been duly cited, this is a research project carried out by me under the supervision of Prof. David Atta-Peters and Dr. Patrick Asamoah Sakyi. This work has not been submitted either wholly or partial anywhere for the award of a degree.

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DEDICATION

This work is dedicated to the almighty God for his endless blessings, protection and kind mercies throughout my life and most importantly during the period of this study. It is also dedicated to all my relatives and loved ones especially the Domapielle family for their support and love during this period.

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Most thanks to the almighty God for his mercies and blessings throughout the duration of the course. Without him, I would not have gotten the strength and will to carry on.

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ACRONYMS

CA	Cluster analysis
CSIR	Council for Scientific and Industrial Research
CWSA	Community Water and Sanitation Agency
DMTDP	District Medium Term Development Plan
EC	Electrical Conductivity
FA	Factor Analysis
GIDA	Ghana Irrigation Development Authority
GIS	Geographic Information System
GRWP	Ghana Rural Water Project
HCA	Hierarchical cluster analysis
JICA	Japan International Cooperation Agency
MDG	Millennium Development Goal
MH	Magnesium hardness
NEPAD	New Partnership for Africa's Development
PCA	Principal Component analysis
RSC	Residual sodium carbonate
SAR	Sodium adsorption ratio
STK	Sawla Tuna Kalba
TDS	Total dissolved solids
TH	Total hardness
WHO	World Health Organization
WRC	Water Resources Commission
WQI	Water quality index

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ABSTRACT

The climate of the Sawla Tuna Kalba District is the tropical continental type where only one rainy season in a year, occurs between early May and late October this makes surface water resources insufficient in the area. Groundwater is the main water supply in this region the utilization of groundwater for various purposes is common. In this part of northern Ghana, groundwater serves as a major source of freshwater for domestic and agricultural purposes. This study investigated the quality of groundwater from 87 boreholes in the Sawla-Tuna-Kalba District of the Northern Region, to promote and enhance the proper utilization of the resource. Samples were collected and analyzed for various water quality parameters to evaluate its usefulness for domestic and agricultural use.

Results indicates that groundwater in the study area is generally fresh and hard. It was found that majority of samples belong to the Ca- Mg-HCO3 hydrochemical facies. Sodium Adsorption Ratio (SAR) for all groundwater samples in the district ranged from 0.175-2.70 (mean 1.00), implying that all the boreholes samples had excellent water that could be used for irrigation. This was confirmed by analytical data plot on the US salinity diagram which illustrated that majority of groundwater samples fall in the field of C2S1; indicating medium salinity and low sodium water. The total hardness (TH) values ranged from 57.94 to 641.2 mg/l with an average value of 187.1 mg/l. The classification of groundwater based on (TH) shows that a majority of the samples fall within moderately hard to hard water category.

Though many of the analysed parameters fall within acceptable range and thus most of the boreholes have water which are chemically suitable for drinking, a few recorded total iron,

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manganese, lead, arsenic and fluoride concentrations above permissible WHO levels, suggesting some concern in terms of potability, especially since such water sources are extensively patronised by inhabitants for drinking and agricultural purposes.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 BACKGROUND

The availability of quality water in good quantities for industrial, agricultural and domestic uses is key to the development of any nation. Groundwater has been considered to be a vital resource of water supply for about a third of the world's population (Nickson et al., 2005). More than 50% of the water requirements of developed countries like the USA, Germany and Denmark are derived from groundwater resources (Trauth and Xanothopoulous, 1997; Mato, 2002).

Ghana as a developing country is challenged with providing adequate quality water to meet the millennium development goals by 2015. This challenge is even more daunted in northern Ghana where poverty and one short rainy season regime are dominant. Surface water sources are less and as such most agencies place emphasis on well-siting techniques to meet the potable water requirements (Apambire, 2000). The reliance of ground water development in these areas is compelled by the following reasons:

a) Groundwater is believed to be more potable and safer than surface water due to the protective qualities of the soil cover (Mishra et al., 2005).
b) It is also a good option to meeting the potable water needs of northern Ghana because of its low price relative to the costs of treating surface water resource. Dapaah-Siakwan and Gyau-Boakye (2000) noted that for communities with less than 5000 people, cost of treating surface water resources is appropriately twice that of developing ground water resources. Similarly, Yidana et al. (2008) noted that the popularity of groundwater resources as the solution to rural water supply systems are because;

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(i) Aquifers underly geographically large areas in the country and these can commonly be tapped at shallow depths.

(ii) Secondly, water stored in aquifers in most parts, is protected naturally from evaporation and yields well to provide water security and

(iii) With adequate aquifer protection, ground water has an excellent microbiological and chemical quality and it therefore requires minimal or no treatment and

(iv) Cheaper than treating surface water.

From the above, groundwater resource development is the most feasible way forward to meeting the potable and agricultural water needs of rural Ghana. However, the development and efficient management of groundwater resources requires a good understanding of the hydrochemical properties of the rocks that underlie these areas.

Agriculture has a central socioeconomic position in Ghana. This sector accounts for about 65 percent of the work force, about 40 percent of the gross domestic product, and about 40 percent of foreign currencies acquired through exports. Although agriculture is a key part of the country's economy, the structure of the sector is vulnerable because it relies on rain fed agriculture during a roughly six-month rainy season. Droughts and other types of unseasonable weather pose risks for farmers. Under these conditions, irrigation development offers the promise of greater food security and the rural-area development by ensuring yearlong agricultural production (Regassa et al., 2011).

Freshwater resources are pivotal to key economic and social activities such as water supply and sanitation, agriculture, industry, urban development, hydropower generation, inland fisheries, transportation and recreation among others. These activities provide employment and generate

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revenue that sustains many economies of the world. Besides its economic value, freshwater plays an important role in addressing issues of health, poverty and hunger and has been rightly recognized in the formulation of the United Nations' millennium development goals (Obuobie and Boubacar, 2010).

Obuobie and Boubacar (2010) indicated that Ghana is well watered with high annual rainfall varying from 800 to 2200 mm and a dense system of rivers and streams with 10 major rivers and several perennial springs located in the forested highland areas. However, the rainfall is highly variable between the wet and dry season as well as from one place to another. The northern part of the country, for example, experiences a prolonged dry season of about 7 months with high evaporative losses and as a result many of the rivers and streams dry up before the dry season is over. For these reasons, surface water supplies are unreliable and insufficient to meet the water demand for socio-economic development. Besides, many of the surface water sources, particularly those used by small towns and rural communities have serious health risks with regard to water-related diseases such as bilharzias, cholera and guinea worm (WARM, 1998).

Groundwater sources have become the preferred means of supplying water to meet the growing demand of the largely rural and dispersed communities and small urban towns in the country. Generally, the chemical and microbiological quality of groundwater is better than that of surface water. Groundwater supply is usually less expensive to develop than surface water and it is more easily expanded at a future date by simply adding new boreholes (Bannerman, 1975). Compared to surface water, groundwater responds more slowly to climate variability and change thereby making it less vulnerable to drought conditions. In addition, groundwater is much easier to

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protect from biological contamination and, in cases where such contamination has been identified, it is easy to disinfect (WARM, 1998).

Throughout Ghana, groundwater is mostly used for domestic water supply. However, the need for irrigation as a result of variability and change in the amount and pattern of the rainfall coupled with the demand for increased agricultural production to feed the growing population of the country has made it a necessity to diversify groundwater use to include dry season irrigation, poultry and livestock watering and fish farming. The use of groundwater in agriculture has the potential to alleviate poverty and improve the food security of the people involved (Obuobie and Boubacar, 2010).

Kyei-Baffour and Ofori (2006) indicated that Ghana could not achieve economic growth and poverty reduction targets without significant improvement in the agricultural sector. Growth in agriculture may be achieved both through extensification (putting more land under cultivation) and intensification (increasing the productivity of existing land). In most cases, irrigation is central to increasing productivity of existing agricultural land.

Ghana is endowed with sufficient water resources for irrigation-based intensification. Estimates of Ghana’s irrigation potential are wildly divergent, ranging from 0.36-1.9 million hectares to slightly more than 33,000 ha under irrigated cultivation (Agodzo and Bobobee, 1994). Irrigation development in Ghana has been justified as a way to achieve food security, poverty reduction, and rural employment (Regassa et al., 2011). This argument is specifically relevant to the three regions in northern Ghana, as they are characterized by mono-modal highly variable rainfall

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distribution. Despite irrigation's considerable potential and the emphasis placed on it in recent Developmental Strategies, the proportion of potential irrigable land actually under irrigation is insignificant. In addition, the performance and productivity of existing irrigation schemes, particularly those that were publicly developed, are generally low (GIDA and JICA, 2004).

This study, therefore, seeks to analyze the chemical properties of ground water in the Sawla-Tuna-Kalba District in the Northern Region of Ghana.

1.2 PROBLEM STATEMENT

Globally, rural water lags behind that of urban areas in terms of quality and supply and this is manifested in West Africa (Fianko et al., 2010). While water needs in urban Ghana are met through the collection, treatment and purification of surface water from rivers, over 90% of rural potable water supply is met through groundwater development (WRC, 2012).

Faced with the challenges of providing potable water to less rural citizenry and small towns, the Community Water and Sanitation Agency (CWSA) was formed by Act 564 in 1998 with the mandate to facilitate the provision of safe drinking water and related sanitation services to rural communities and small towns in Ghana. The agency has since relied heavily on groundwater to meeting its mandate. For instance, as at December 2006, the agency, with the support of her Development Partners delivered 17,565 boreholes, consisting of 9,945 newly constructed, 3,398 rehabilitated and 4,224 converted boreholes. In addition, 1,333 hand-dug wells were constructed whiles 87 were rehabilitated within the period (CWSA, 2008).

About 95% of potable water delivery is through ground water. This is not without quality problem. According to CWSA's brochure, about 20% of boreholes drilled for domestic purposes contain high concentration of fluoride, manganese and iron compounds above the Ghana Standards Authority permissible limits of 1.5 mg/l (fluoride) 0.01 mg/l (manganese) and 0.03 mg/l (iron) in some regions of Ghana.

1.3 STUDY OBJECTIVES

The overall objective of this study is to assess the quality of groundwater from selected boreholes in the Sawla-Tuna-Kalba District and its suitability for domestic and agricultural purposes. It is also to determine the factors and/or activities affecting the quality of ground water in the District. The specific objectives however are:

- To evaluate the chemical and physical characteristics of groundwater resources from boreholes in the Sawla-Tuna-Kalba District.
- Determine the general water quality of the ground water resources;
- Determine the major groundwater control reactions;
- Determine the major water types in the study area

1.4 JUSTIFICATION

Water is a basic necessity for sustainable livelihood. Provision of good quality water is unquestionable if Ghana is to meet her millennium development goals by 2015. The increasing population of Ghana has even made the provision of quality water for both rural and urban areas more challenging. The Water Resources Commission has estimated that the consumptive water demand for 2020 is projected to be 5.13 billion m^3 (WRC, 2012). Much of this water demands is being met especially in the rural areas through the construction of boreholes by Non-Governmental Organizations and state Agencies like the World Vision Ghana Rural Water Project (GRWP) and Community Water and Sanitation (CWSA). Even though there may be enough groundwater the chemical composition of the water would determine its suitability for domestic and agricultural uses. Water quality affects health and agricultural development of every society; hence the need for this study.

This study seeks to contribute to understanding the hydrochemistry of the water so as to advice its implication for human consumption and for agricultural purposes. It would also establish the hydrochemical processes that affect water quality in the area.

1.5 PROFILE OF THE STUDY AREA

1.5.1 Location and Accessibility

The Sawla-Tuna- Kalba District is a young one carved out of the then Bole District in 2004. It is one of the twenty districts in the Northern Region of Ghana. The district is located in the western part of the Northern Region (Fig. 1.1), between latitudes 8 ^{o} 40’ and 9 ^{o} 40$^{’}$ North and longitudes

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1^{o} 50’ and 2^{o} 45$^{’}$ West (Ghana Districts, 2012). The district shares common boundaries with Wa West District and Wa East to the North, Bole District to the South, West Gonja District to the East and Cote d’Ivoire and Burkina Faso to the West. It has a total land area of about 4,601 square km out of the total area of 74,984 km of the Northern Region, representing six point fourteen percent (6.14%) of the total land mass of the Northern Region. Sawla, the district capital is about 210 km northwest of Tamale, the regional capital in the Republic of Ghana (DMTDP, 2010).

1.5.2 Population Dynamics

The total population is estimated to be 94,664 (DMTDP, 2010).). This population is made up of 49,064 female and 45,600 male. Out of the total population, eighty-five percent (85%) of the people lived in the rural areas and fifteen percent (15%) lived in the urban areas. It is worthy to note that Sawla, Tuna, Kalba and Gindabou are the settlements which qualify as urban areas since their respective populations are above 5000. The population of the district is evenly distributed with the population density increasing from 8 persons per sq. km in 1984 to 14 persons per sq. km in 2000. The growth rate of the district is 3.1% which is slightly higher than the national growth rate of 3.0%. There are 278 communities in the district with varying populations (DMTDP, 2010).

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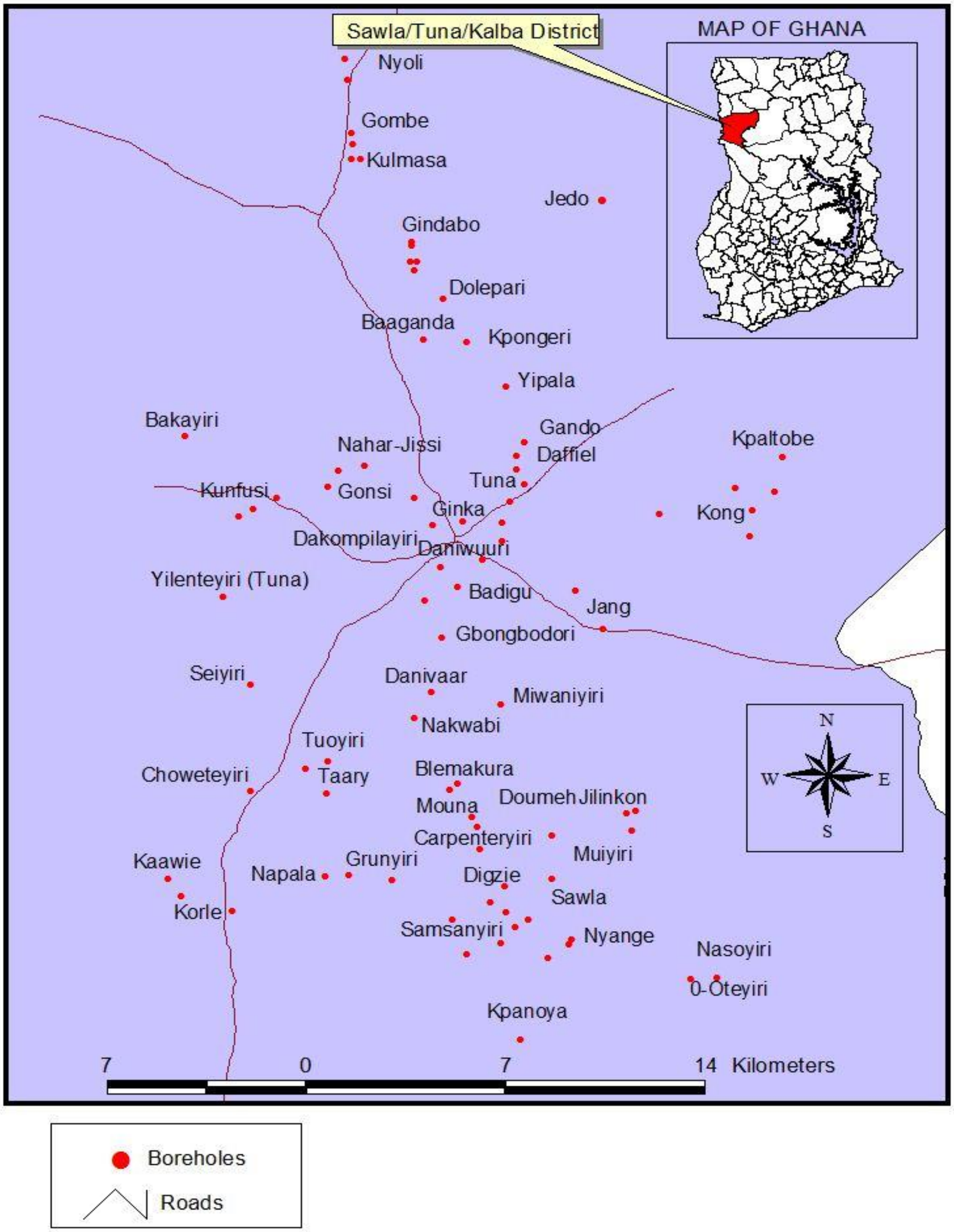

Fig. 1.1 Map of Sawla-Tuna-Kalba District (Ghana Districts.com)

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1.5.3 Vegetation and Soil

The predominant vegetation found in the District is just like any other part of the Northern Region. It is mainly Guinea savanna woodland with wide spread of the trees. Some of the common trees found in the District are sheanut, dawadawa, teak, kapok and mango (DMTDP, 2010). The natural vegetation of Sawla-Tuna-Kalba district has disappeared, especially around the settlements; this was due to the interference by man and animals through cultivation, grazing and exploitation for fire wood. In the dry season, the grasses in most part of the district are periodically burnt down to either clear the land for cultivation or hunting of animals (DMTDP, 2010). These activities have deprived the land of much vegetation cover and nutrients. These therefore affect food production in the district.

The District has soils of varied nature, occurring in complex associations. The predominant soil types found in the District are light textured surface horizons in which sandy loans and loans are common. Most of the soils contain abundant course material either gravel or stone which adversely affect their physical properties particularly their water holding capacity. The soil is generally very fertile for agricultural cultivation (DMTDP, 2010).

1.5.4 Physiography

The drainage system of the district is like most rural and Savanna areas. The Black Volta River drains the area through several tributaries such as the Gbongbon, Mole, Dagbu and Kongpe streams. Dickson and Benneh, (2004) describes the area to fall within the Tropical Continental or Interior Savannah climatic zone. There is only one rainy season in a year, which occurs between early May and late October. The highest rainfall is experienced between July and September.

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The monthly main rainfall ranges between 200 mm and 300 mm. The period between November and April is the dry season. This season is characterized by the cold harmattan winds with concomitant airborne diseases. In terms of temperature, the district experiences extremes of it.

The daily and annual range of the temperature is wide. The coldest nights in the year are experienced in the months of December, January and February. During this period the air becomes dry and the atmosphere becomes hazy and one cannot see clearly due to the fine dust in the air. The day temperature within the same period are between 28^{o}C and 40^{o}C but under cloudiness skies, the night can be very cold with temperature under 28^{o}C. The temperatures suddenly rise in the months of March, April and May when temperature exceed 30^{o}C. The nights are usually hot and people prefer to cook, eat and sleep outside. But when the rain start the mean temperature begins to fall again (DMTDP, 2010).

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CHAPTER TWO

LITERATURE REVIEW

2.1 HYDROCHEMISTRY

With about 7 x10^{12} m^3 of water drawn from the world's aquifers each year, ground water is by weight the most extracted raw material from the east (Jean-Claude, 1995). 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 Elagovan, 2009). It therefore means that even though groundwater is a common resource, the chemical properties of the water would determine its suitability for use. The World Health Organization (WHO, 2004) guideline limits of water potability should be the guideline in determining the hydrochemistry of potable water.

In northern Ghana, the reliance on groundwater exploration through hand dug wells and boreholes because of their suitability calls for an examination of the potability of these boreholes and dug wells. 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. 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, on exchange, concentration and other chemical reactions (Schoeller, 1997).

Groundwater hydrochemical and isotopic (^{18}O and ^{2}H) 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), and the Keta basin (Yidana et al., 2010) where the natural weathering of fluorite and seawater intrusion respectively elevate fluoride and salinity levels 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

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). Water with percent sodium above

85% and EC above 3000 µS/cm were considered poor, the ones with EC above 5000 were considered very poor and the ones with sodium percent below 85% and EC below 3000 µS/cm were poor to excellent. They concluded that water of undesirable quality may be used successfully when the undesirable aspects of the water are off-set by certain desirable aspects of the water or positive conditions of its use. These aspects included gypsum content of the water and/or soil, soil characteristics, effective rainfall, water table level, type of crop and gypsum additions. Deutseh (1997) notes that in the assessment of water chemistry, inorganic constituents are classified as major ion constituents with concentrations greater than 10 mg/l, where as trace elements are those with concentrations less than 0.01mg/l. These ions could be cations (positively charged) and anions (negatively charged). The major cations include sodium (Na^+), potassium (K^+), calcium (Ca^+) and magnesium (Mg^{2+}) and the major anions include chlorine (Cl^-), sulfate (SO_4^{2-}), fluoride (F^-) and nitrate (NO_3^-). 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) and references therein, 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. 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. These calculated values are then compared to a standard range for inference.

If w_i = standard weight

W_i = relative weight

C_i = concentration/ value of a parameter

S_i = World Health Organization (WHO, 2004) standard for the parameter

Then, the WQI is computed using the following equations sequentially:

$$Wi = \frac{wi}{(Wi)} \tag{2.1}$$

$$qi = \frac{Ci}{(Si) \times 100} \tag{2.2}$$

Therefore, the q_i value computed per sampling point is then summed to obtain WQI for the whole area.

Table 2.1 Proposed keys for making inference in the Classification of water (Sahu and Sikdar, 2008)

Concentration (mg/l)	**Water Class**
<50	Excellent water
50-100	Good water
100-200	Poor water
200-300	Very Poor Water
>300	Water unsuitable for use

Table 2.2 Weight (W_i) and relative weight (W) of parameters used in computing the WQI

Parameters	**WHO Standard**	**Wi**	**W**
pH	7.5	4	0.129
SO4	250	3	0.097
Cl	250	3	0.097
NO3	50	5	0.161
F	1.5	5	0.161
Ca	75	2	0.065
mg	30	2	0.065
Na	200	2	0.161
EC	1,500	5	1
	Total	**31**	

However, another form of determining WQI of water resources was carried out by modifying CCME (2001) and the resulting relation used to compute for the safety of water in the Keta basin for domestic use (Yidana et al., 2010). It was concluded that most of the water fell within the fair range. A distribution map was also derived from the analysis. In this analysis, WQI was computed by using the relation:

$$WQI = 100 - \frac{\sqrt{F1^2 F2^2 F3^2}}{(2)} \tag{2.3}$$

Where; F1 refers to the percentage of samples whose variables depart from the WHO values.

F2 expresses the percentages that do not meet the WHO standard.

F3 is the extent to which the deviated parameters exceed the standard values.

Sodium Adsorption Ratio (SAR) is a measure of the suitability of groundwater for irrigation purpose. It was designed by Karanth (1987) to measure the effect of sodium on crops and is computed by the relation:

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$$\text{SAR} = \frac{2 \text{ x Na} +}{\sqrt{Ca2 + + Mg2 +}} \tag{2.4}$$

The sodium content of the water can also be expressed as a percentage as follows:

$$\%\ \text{Na} = \frac{Na}{Na + Ca + Mg + K} \times 100 \tag{2.5}$$

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.

Aside the estimation of sodium content using SAR and percentage sodium to determine the favourability of water for irrigation, the excess sum of carbonate and bicarbonate over the sum of calcium and magnesium referred to as Residual Sodium Carbonate (RSC) can also be use to predict the suitability of groundwater for crop irrigation (Ragunath, 1987);

$$\text{RSC} = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \tag{2.6}$$

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 Na^+ and bicarbonate concentration relative to the total cations present in the water. It is computed by the equation (Subramani et al., 2005):

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$$PI = \frac{\left(Na^{+} + \sqrt{HCO_3^{-}}\right) \times 100}{\left(Ca^{2+} + Mg^{2+} + Na^{+}\right)} \qquad (2.7)$$

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).

Ajayi and Umoh (1998) stated that Sodium Adsorption Ratio (SAR) is used to determine the suitability of water for irrigation of agricultural land. Hem (1985) also noted that the combination of specific conductance and SAR is used to determine the suitability of water for irrigation and that a specific conductance near 2000 µ/cm at 25^{o} and a SAR greater than 10 would represent a high sodium hazard (Anku, 2007).

Fehdi (2009), on the basis of differentiation, analyzed the behavior of certain ions using chloride ion, which is considered to be a conservative tracer of the salt water intrusion process from Plioquaternary aquifers in Algeria. Binary Relationship diagrams between Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-} and Cl^{-} helped him to conclude that:

(i) The water in the region of Morsott (in the South of the study area) constituted a separate chemical group. The fresh water generally had an excess of Ca^{2+} accompanied by a deficit in Na^{+}. This situation could be attributed to a process of inverse exchange.

(ii) The saline water from the rest of the aquifer (i.e., Boukhadra and Mesloula areas) reflected an increase in Na^{+}, which corresponded to deficits in Ca^{2+}, a situation, which is related to direct ion exchange.

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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 (HCO_3^-) and carbonate (CO_3^-) and acidity of water generally is expressed in terms of hydrogen ion (H+) (Walton, 1970). The extent to which water is alkaline or acid determines the quality and the purpose for which it could be used. Various methods and techniques have been used by several workers to analyze water chemistry. Some of these techniques are described in the subsequent sections.

2.2 GRAPHICAL TECHNIQUES

Groundwater chemical interpretation can be done using graphical displays like piper diagrams, stiff patterns and diagrams, flow path observation or molar relationships. Mahlknecht et al., (2004) however noted that even though graphical representations are very helpful in the preliminary evaluation of ground water types and of the relationships between ground water and lithology, the graphical display has the following setbacks;

a) The graphical display deals with limited number of chemical elements and therefore appears subjective in the interpretation as one would have to choose which element to represent (Guler et al., 2002).

b) Secondly, flows path configurations are only possible if selected samples intersect and this is only possible where there is an appropriate calibrated ground water flow model of the study area (Parkhurst et al., 1996). Despite these inadequacies about the graphical method, graphical method remains a preferable technique for analyzing ground water chemistry for many. In Ghana, Yidana et al. (2009) used the technique to characterize the

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hydrochemistry of ground water in northern Volta. The study revealed ground water hydrochemistry is controlled by silicate and carbonate minerals and that cation exchange was observed and the geology appeared to have a great impact on the quality of water in the study area with low cation exchange effect.

Pelig-Ba (1998) used descriptive statistical methods to explain that groundwater from some crystalline rocks in the Upper East Region indicate higher trace element concentrations as compared to their concentrations found in natural water systems. Finanko et al. (2010) used the method to show that ground water in his studied area is fresh and generally suitable for resources.

Graphical Methods form one of the conventional approaches used in presenting chemical data of major ions that typifies groundwater. Hem (1985) says graphing is 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.

The techniques are used to identify water samples with similar chemical composition and group them since samples with these similar characteristics often bear similar hydrologic background, originate from similar recharge areas, and have the same infiltration pathways and flowpaths 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 analyzed 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.

Yidana et al. (2010) used the averages of the chemical parameters in the four clusters of the Keta basin to plot Schoeller diagrams to observe that the differentiation in the cluster analysis is therefore associated with the EC values, which are dictated by the major influences in the hydrochemistry and that the static water levels do not appear to be correlated with salinities among the clusters defined.

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- 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. 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). In his study, the average concentrations of the major ions were used to describe the different groundwater associations depicted by the four different clusters. In two of the clusters (cluster 1 and 4), the Ca^{2+} cation was the highest among the cations, whilst the bicarbonate ion was the predominant anion. This means that the most predominant water type in cluster 1 and 4

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was the Ca–HCO_3 water type. The uniqueness of cluster 1 over cluster 4 was the relatively higher measures of the major chemical parameters.

In the hydrochemistry of the aquifers in Ghana, the Ca–HCO_3 water type is associated with areas where rock–water interactions are the major causes of variation in the hydrochemistry of groundwater from the major hydrogeological basins. Clusters 2 and 3 both showed the dominance of the monovalent cations over the divalent ones, and the predominance of Cl^- over the rest of the anions. Clusters 2 and 3 were both Na–K–Cl waters, which were characteristic of aquifers that were contaminated by saline water from the Gulf of Guinea and the saline Keta Lagoon. These waters were characterized by relatively high concentrations of the major ions leading to relatively high salinities. Cluster 2 was the more saline of the two.

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.

Yidana (2008) and Yidana et al. (2010) concluded that rock dissolution is a dominant process influencing groundwater hydrochemistry in the major hydrogeological terrains of Ghana. Where silicate mineral weathering is the major controlling process, concentrations of the major physico-chemical parameters are relatively low. Wells constructed within the weathered Dahomeyan gneisses in the Keta basin deliver relatively fresh groundwater whose quality is controlled by the weathering of silicate minerals.

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Clusters that were dominated by the processes of mineral dissolution explained why they present the freshest water types in the area. Clusters that plotted within the ‘‘evaporation-crystallization dominance” field on grounds of high TDS and high Na/Ca + Na ratio were apparently due to elevated TDS and sodium concentration arising from saline seawater intrusion.

The Piper trilinear diagram (Fig. 2.1) is another graphical and widely used method essential for reduction of chemical data. It was developed by Piper (1944) and consist of two equilateral triangles adjacent each other and a diamond-shaped quadrilateral between the two triangles. One of the triangles represents the concentration of major cations which are (Na^+) + (K^+), (Ca^{2+}) and (Mg^{2+}). The other triangle represents the major anions which are (Cl^-), (SO_4^{2-}) and (CO_3^{2-}) + (HCO_3^-). The concentrations of the major ions of a sample expressed as percentage are plotted in the respective triangles and the points extrapolated into the diamond-shape quadrilateral. The location of the extrapolated point in the diamond-shape quadrilateral defines the category of the water. The area within the diamond-shape quadrilateral has been subdivided to represent water-type categories by Back (1961) and Back and Hanshaw (1965).

The water-type classification which has become widely used include: $Ca-HCO_3$, $Ca–Mg-HCO_3$, $Ca–Na-HCO_3$, $Na-HCO_3$, $Na–Ca-HCO_3$, Na-Cl and $Ca–Mg-SO_4$ types. Piper diagrams are more robust than the previous graphical techniques mention earlier on due to its ability to handle more data points. Also the piper diagram serves as the basis for the classification of water types (Back, 1966). Using Piper digrams, Kortatsi (2004) identified four main water types in the study of groundwater in theTarkwa-Prestea area. These are $(Mg+Ca)(HCO3)_2$, $(Mg+Ca)SO_4$, (Na+K)Cl, and mixed water types where no particular ion exceed 50% have been identified.

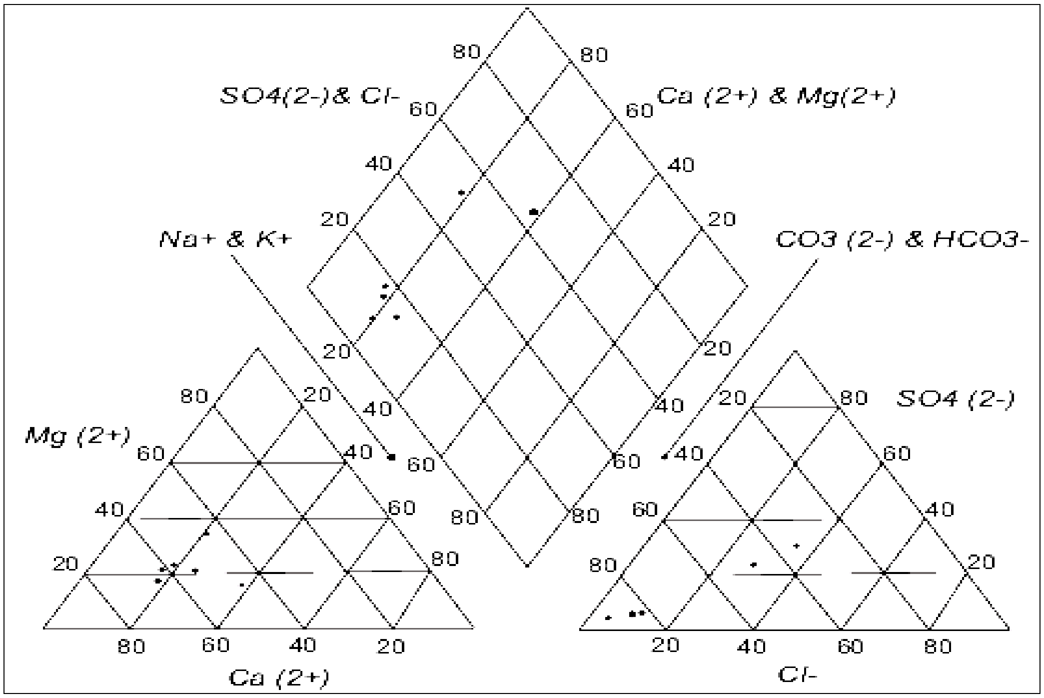

Figure 2.1 A typical piper diagram

2.3 MULTIVARIATE STATISTICAL ANALYSIS

Multivariate statistical analysis generally refers to a range of statistical techniques and methods which primarily involves data with several variables, with the objective of investigating the dependence relations between the involved variables (Hamdan, 2012). It is used to study the variations, relations, distributions of the hydrogeochemical data along the study. Some of the multivariate techniques include Principal Component Analysis (PCA), Cluster Analysis (CA) and Factor Analysis (FA). These are effective techniques of manipulating, interpreting and representing data concerning groundwater pollutants and chemistry (Belkhiri et al., 2010).

Multivariate statistical technique has also been employed to identify the different sources of solutes in groundwater (a) dissolution of calcium and magnesium carbonate minerals, (b) weathering of acid volcanic minerals, (c) alteration of manganese containing alkaline silicates,

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(d) leaching of halite deposits of meteoric origin, (e) contamination from agricultural and urban wastewaters, and (f) evaporative effects due to intensive irrigation (Mahlknecht et al., 2004).

Cloutier et al. (2008) applied two multivariate statistical methods, hierarchical cluster analysis (HCA) and principal components analysis (PCA) to a subgroup of a dataset made up of 144 samples and 14 parameters to evaluate their usefulness to classify the groundwater samples, and to identify geochemical processes controlling groundwater geochemistry. It was revealed that the following factors were recognized as influencing the evolution of groundwater: (i) geological characteristics including sedimentary rock type and till mineralogy; (ii) hydrogeological characteristics represented by the level of confinement and the hydraulic gradient; and (iii) the geological history of the area.

Yidana et al. (2006) applied hierarchical cluster analysis (HCA) and Principal Component Analysis (PCA) to assess the main controls on the chemistry of surface water resources from the Ankobra Basin and concluded that the hydrochemistry of the basin is controlled by the weathering of minerals and the decay of organic matter. Banoeng-Yakubo et al. (2009) applied multivariate and mass balance approaches to study the main determinants of the hydrochemistry of groundwater in some sections of the Volta Region of Ghana. R and Q-mode hierarchical cluster analysis (HCA) are combined with factor analysis with principal components and varimax rotation, to determine field associations among the sample points, and their most possible sources of origin.

Principal Component Analysis (PCA) is also a popular multivariate technique used for the understanding of large quantity of data involved in extended aquifer studies (Invernizzi and Oliveira, 2004). Khan (2011) used PCA and regression analysis to analysis hydrochemical data in the Ganja Basin in India. The PCA used in this study identified five factors that are responsible for the data structure explaining 83.49 % of the total variance of data set. The regression analysis showed that electric conductivity (EC) was an independent variable which could be used to measure (CO_3^{2-}), (Cl^-), (Na^+) and (TDS). Further (Mg^{2+}) can be used to calculate the (TH) directly in the area.

2.4 GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING

Remote sensing and GIS technologies have been recently used by many researchers as very useful tools in the field of hydrogeology. Ashraf et al., (2011) applied GIS for the determination of groundwater quality suitable for crops influenced by irrigation water in the Damghan region of Iran. 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 EC_W 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. The suitable zones for infiltration had no degree of restriction on use in majority on the study area. The maps result of crops yield potential as influenced by irrigation water salinity (EC_w) indicates that crops

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barley>wheat>Alfalfa respectively had yield potential more against EC_w in study area (99.42, 92.30 and 0.23%). The results of thematic maps of $sodium_{w,}$ $chloride_w$ were overlaid with maps of $sodium_{plants}$, $chloride_{plants}$, showed that the crops yield potential of barley and wheat. Alfalfa in all the study area is 100%.

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.

Hydrochemical and stable isotope ($_{18}O$ and $_{2}H$) analyses of groundwater samples are also some techniques used to establish the hydrochemistry of groundwater. Kortatsi (2004) used these techniques to establish that a mildly acidic and low conductivity ground and also silicate mineral weathering were is probably the main process through which major ions enter the groundwater and that groundwater in the area was recharged from a meteoric origin.

Research carried out by Fantong et al., (2008) using Deuterium, $^{\delta}{}_{18}O$, major ions and dissolved silica in groundwater from semi-arid Mayo-Tsanaga river basin in the Far North Province, Cameroon to trace hydrogeochemical processes that control their concentrations and to explore for usability of the water, revealed that the main processes controlling the major ions composition include the dissolution of silicates and precipitation of fluorite and carbonate cation exchange of Ca in water for Na in clay and anthropogenic activities.

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In order to identify the geochemical processes and their relation with groundwater quality as well as to get an insight into the hydrochemical evaluation of groundwater, Fehdi et al. (2009) used chemical and isotopic data to deduce a hydrochemical evaluation of the aquifer system based on the ionic constituents, water types, hydrochemical facies and factors controlling groundwater quality. The increase in salinity was seen to be related to the dissolution and/or precipitation processes during the water–rock interaction and to the cationic exchange reactions between groundwater and clay minerals. Rouabhia et al., (2009) combined chemical and environmental isotope data to determine the origin of dissolved species and of groundwater. It was revealed that, the chemical evolution of groundwater was primarily controlled by water rock interactions. Interpretation of $_{18}O$ and $_{2}H$ also suggested that the recharge of the investigated groundwater may result from different mechanisms.

2.5 GEOLOGY AND HYDROGEOLOGY

The geology of Ghana is dominated by two major formations. These are the basement crystalline rocks associated with the West African Craton and covers 54% of the country and the Paleozoic consolidated sedimentary formation, which was formed in a depression of the West African Craton and covers about 45% of the country (Fig. 2.2). The remaining 1% of the country is underlain by minor geological formations including Cenozoic, Mesozoic, and Paleozoic sedimentary strata along narrow belts on the coast, and Quaternary alluvium along the major stream courses.

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The basement crystalline rocks are of Precambrian age and consist of granite-gneiss-greenstone rocks, phyllite, schist, quartzite, strongly deformed metamorphic rocks and amorogenic intrusions (Key, 1992). Generally, the structural trend in these basement rocks is influenced by the principal tectonic stress orientation and therefore follow a northeast-southwest (WNW-ESE) axis (Apambire, 1996). The basement crystalline formation is commonly subdivided into the Birimian group (with associated granitoid intrusions), Granite, Tarkwaian Group, Dahomeyan Formation, Togo Formation and the Buem Formation (Obuobie and Boubacar, 2010). The Birimian group dominates the basement crystalline formation and covers densely populated areas including most of western, south-central, northeast and northwest of the country and can be as thick as 15,000 m (Key, 1992).

The Paleozoic consolidated sedimentary formations are locally referred to as the Voltaian formation and consist mainly of sandstone, shale, arkose, mudstone, sandy and pebbly beds, and limestone (WARM, 1998). Based on lithology and field relationships, the Voltaian formation can be sub-grouped into the upper, middle and lower Voltaian. The upper Voltaian consists of massive and thin-bedded quartzite sandstones, which are interbeded with shale and mudstone in some areas. The middle Voltaian (Obusum and Oti Beds) mostly comprise of shales, sandstones, arkose, mudstones and siltstones. The lower Voltaian consists of massive quartzite sandstone and grit (Obuobie and Boubacar, 2010).

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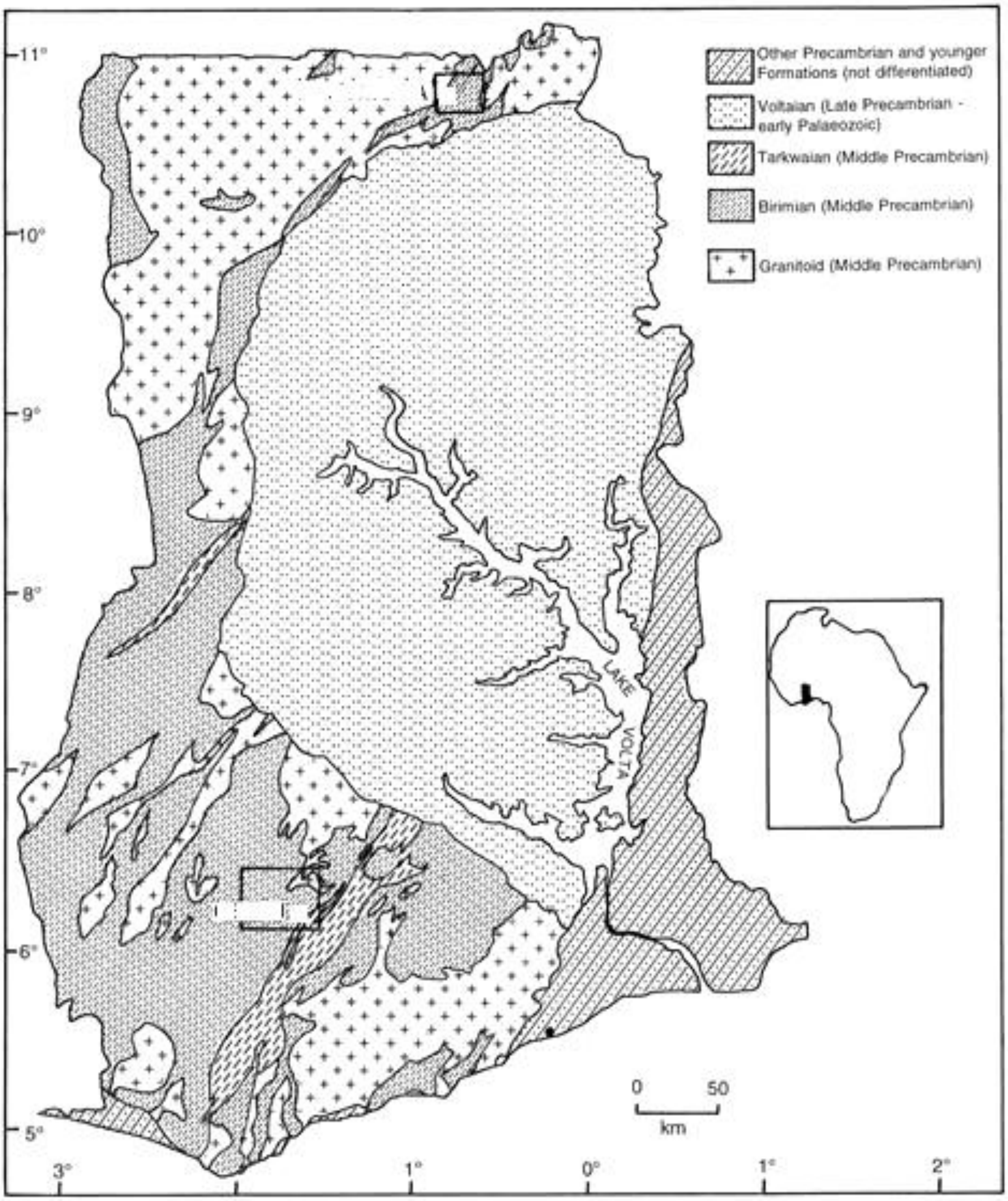

Figure 2.2: Geological map of Ghana (Ghana Geological Survey)

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The Cenozoic, Mesozoic, and Paleozoic sedimentary strata (minor geological formations) are made up of two coastal formations, namely, the coastal Block-Fault and the coastal plain. The coastal block-fault consists of a narrow discontinuous belt of Devonian and Jurassic sedimentary rocks that have been broken into numerous fault blocks and are transected by minor intrusives (Obuobie and Boubacar, 2010). The coastal plain formation is underlain by semi-consolidated to unconsolidated sediments ranging from Cretaceous to Holocene in age in south-eastern Ghana and in a relatively small isolated area in the extreme south western part of the country (WARM, 1998). The other minor formation, alluvia, comprises of narrow bands of alluvium of Quaternary age, occurring principally adjacent to the Volta River and its major tributaries and in the Volta delta (Dapaah-Siakwan and Gyau-Boakye, 2000).

The major geological formations in the country are overlain by the so-called regolith, which is a weathered layer that varies in thickness and lithology (Martin and Giesen, 2005; HAP, 2006). The thickness of the regolith is influenced by lithology, structural characteristics, topography, vegetation cover, erosion, aquifer characteristics and climate. In the Precambrian formation the thickness varies widely with an average ranging from 2.7 to 40 m but can be up to 140 m in the extreme northwest of the country (Apambire, 1996; Smedley, 1996; Apambire et al., 1997). Generally, the regolith in the Voltaian formation is less thick compared to the Precambrian formation and ranges from 4 to 20 m in the southern part (Acheampong, 1996).

The District is underlain primarily by granitic rocks, which constitute over 80% of the basement rocks. Lower Birrimian rocks made up of phyllite, schist, tuf and greywacke occur in the southwest and the northeast whilst Upper Birimian rocks comprising metamorphosed lavas and pyroclastic rocks underlie the south-eastern portion of the area. Basal sandstone of the Lower Voltaian System also underlies the extreme northeast section of the district. The basement rocks have very little intergranular pore space and are thus characterized by negligible primary porosity and permeability. Where the rocks occur near the surface, they are usually fractured and weathered and acquire considerable secondary porosity within the regolith. They may also contain openings along joints and fissures, bedding and cleavage planes. When these openings are extensive, continues and/or interconnected, and are not filled with impervious material, percolation of considerable water might occur to form groundwater reservoirs (Darko et al., 2003).

2.6 GROUNDWATER QUALITY

Available data from previous studies (e.g., Amuzu, 1975; Andah, 1993; Kortatsi, 1994; WARM, 1998; Darko et al., 2003) indicate that the quality of groundwater abstracted via boreholes in Ghana is generally of good chemical and microbiological quality and therefore suitable for domestic including drinking, agriculture and industrial uses (Table 2.3). There are, however, groundwater quality problems in certain localities. The problems include low pH (3.5-6.0) waters found mostly in the forest zones of southern Ghana, high concentration of iron in many places throughout the country, high concentration of manganese and fluoride mostly in the north of Ghana as well as high mineralization with TDS in the range 2000-14,584 mg/l in some coastal aquifers (Kortatsi, 1994). Most of these problems can be attributed to geochemical processes taking place in the bedrock of aquifers, anthropogenic activities or sea water intrusion in the case of high concentration of sodium chloride in coastal aquifers. A summary of potential groundwater quality problems in Ghana are presented in Table 2.4

The hydrogeological conditions are based on the presence and intensity of weathering and fracturing due to the absence of primary permeabilities in the rocks. There is an average success rate of 56% in drilling boreholes within these rocks (Gyau-Boakye and Dapaah-Siakwan, 2000).

Table 2.3: Summary of water quality in geological formations of Ghana (Kortatsi, 1994)

Parameters	Gneiss	Granite	Phyllites	Sandstone	Mudstone and shale	Sand and gravel	Limestone	Quartzite
pH	7.5	6.99	6.83	6.95	7.64	7.53	7.7	6.36
Total dissolved salts	4888	387.38	211.19	533.45	424.66	632.04	946.77	398.26
Calcium	595	49.38	32.09	25.08	26.1	68.72	58.08	42.06
Magnesium	207.2	19.06	15.67	7.57	9.12	33.5	36.14	23.37
Sodium (Na)	720	47.99	11.67	262.55	125.39	134.45	296.77	24.53
Chloride (CI)	1790	73.48	9.9	70.42	42.04	173.56	196.86	103.61
Sulphate ($S0_4$)	1800	10.6	7.16	65.17	11.18	101.19	77.25	60.06
Bicarbonate ($C0_3$)	34	81.17	104.14	97.49	189.29	154.59	149.66	67.05
Total iron (Fe)	0.1	1.01	2.15	1.95	0.645	1.84	0.467	2.87
Manganese (Mn)	0.05	0.44	0.39	0.17	0.1	0.22	0.16	0.45
Fluoride (F)	0.25	0.35	0.315	0.775	0.57	0.6	1.76	0.23
Nitrate nitrogen	0.5	1.605	0.59	0.75	0.135	2.22	1.79	2.32
Total hardness	2340	172.49	123.7	70.76	222.77	230.35	229.94	179.61

Table 2.4: Summary of potential groundwater-quality problems in Ghana (BGS)

Determinand	**Potential Problem**	**Geology**	**Location**
Iron (Fe)	Excess,often significant	All aquifers	Many locations
Manganese (Mn)	Excess	All aquifers	Several locations
Flouride (F)	Excess (up to 4 mg/l)	Granitesand some Birimian rocks	Upper Regions
Iodine (I)	Deficiency (less than 0.005 mg/l	Birimian rocks, granites, voltain	Northern Ghana (especially upper regions)
Arsenic (As)	Excess (>0.01 mg/l)	Birimian Especially south-west	Ghana (gold belt)

Borehole depths are between 21.0 m and 99.0 m with yields ranging between 0.3 m^3/h and 12.0 m^3/h. In the area, aquifer transmissivity among the sandstones is in the range of 0.1-52.0 m^2/d. In the siltstone and mudstone aquifers, transmissivity is in the range of 0.2-16.0 m^2/d. Generally, there is a strong relationship between aquifer transmissivity and specific capacity among the Voltaian aquifers in Ghana (Yidana et al., 2008b).

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CHAPTER THREE

RESEARCH METHODOLOGY

3.1 SAMPLE COLLECTION

Sampling and field measurements were all done by hydrogeologists from Community Water and Sanitation Agency Northern Region, Ghana. Samples were collected from 87 boreholes from the predominantly granitic formation in the study area. Sampling protocols described by Claasen (1982), Barcelona et al., (1985) and Gale and Robins (1989) were strictly observed during sample collection. Each sample was collected in 100 ml acid-washed high-density linear polyethylene (HPDE) bottles. To remove particulate matter from samples, filtering was performed using a Sartorius polycarbonate filtering apparatus and a 0.45-µm cellulose acetate filter membrane. The sample meant for cation analyses was immediately acidified to a $\text{pH} < 2$ after filtration using reagent grade nitric acid while those for anion analyses were without preservation.

3.1.1 Field Measurements

For all samples collected, parameters such as electrical conductivity (EC), temperature (T) and pH values were measured in the field. On-site testing was necessary for these parameters since they are likely to change during transport. The variables were measured using TW-Multiline P4 Universal Meter in flow-through cell attached in line to the borehole pump outlet. Before taking readings, pumping was carried out until the meter readings were stable for each parameter.

3.2 LABORATORY ANALYSIS

All major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-}), as well as minor elements, such as NO_3^-, and F^-, were analysed using Dionex DX-120 ion chromatograph at the water quality laboratory of Water Research institute - CSIR, Tamale. The bicarbonate ion concentration in the water was determined by titration. In accordance with international standards, results with ionic balance more than 5% were rejected. The TDS was estimated by summing up all the major cations and anions in the sample using the Microsoft Excel software. The sodium adsorption ratio (SAR), which indicates the effect of relative cation concentration on sodium accumulation in the soil was also calculated from the relationship (Fetter, 1994):

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

Where Na^+, Ca^{2+} and Mg^{2+} are in meq/l.

While the Magnesium hazard (MH) was calculated using equation (2) (Szabolcs and Darab, 1964):

$$MH = 100\ Mg\ (Ca^{2+} + Mg^{2+})^{-1} \qquad (3.2)$$

Where Ca^{2+} and Mg^{2+} are the concentrations of the respective ions expressed in milliequivalent per liter (meq/l). The total hardness of groundwater samples was determined using the following equation (Todd, 1980):

$$TH = 2.5Ca^{2+} + 4.1Mg^{2+} \qquad (3.3)$$

Where TH is the total hardness as $CaCO_3$ in mg/l; Ca: Ca^{2+} and Mg: Mg^{2+}concentrations in mg/l.

$$meq/L = (\text{Concentration in mg/L})/(\text{Atomic weight of ionic species})/(\text{number of charges}) \quad (3.4)$$

Percent sodium was calculated with the formula:

$$\%Na = \left[\left(Na^{+} \times 100\right)/\left(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}\right)\right] \times 100 \quad (3.5)$$

where the quantities of Ca2+, Mg2+, Na+ and Mg+ all expressed in meq/L.

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CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 HYDROCHEMICAL ANALYSIS AND EVALUATION OF GROUNDWATER QUALITY

4.1.1 Physiochemical Analysis

The results of physico-chemical analysis of groundwater samples from the Sawla Tuna Kalba are summarized in Table 4.1.

Table 4.1 Summary of groundwater chemical parameters in the study area

Parameters	Minimum	Maximum	Mean	SD	WHO (2003) Guideline
pH	6.09	9.81	6.94	0.49	6.5 - 8.5
Conductivity (µS/cm)	102	1486	452.2	287.9	1400
Sodium (mg/l)	6.3	79.3	25.3	14.4	200
Potassium (mg/l)	0.6	9.3	4.1	2.1	30
Calcium (mg/l)	8	131	36.7	22.5	200
Magnesium (mg/l)	3.4	94.2	23.3	15.2	150
Fluoride (mg/l)	0.1	1.9	0.6	0.3	1.5
Chloride (mg/l)	4	131	19.5	23	250
Sulphate (mg/l)	2.6	90.8	12.2	13.3	250
Nitrate (mg/l)	<0.01	7.01	1.37	1.61	50
Bicarbonate (mg/l)	61	515	232.1	98.6	-
Total Alkalinity (mg/l)	50	422	190.3	80.85	400
Total Hardness (mg/l)	57.94	641.22	187.1	99.8	500
Total Dissolved Solids (mg/l)	42.3	740	232.8	148.6	1000

The physical observations of the samples indicated that they are odourless and colourless in nature. The pH of groundwater in the study area varied from 6.1 to 9.8, which were generally within WHO (2004) recommended limit of 6.5-8.5 for potable water. A few samples, however, recorded slightly acidic as well as alkaline conditions. Spatially, borehole water from Nyoli (6.09), Gombe (6.22), Nakpala (6.34), Nasoyiri (6.38) and Baaganda (6.48) were slightly acidic, whiles Kpongeri 2 (9.81) was slightly alkaline. Boreholes with low pH levels have the potential to enhance corrosion of pump parts but may not affect its use for domestic purposes. Slightly acidic groundwater may also enhance the dissolution of trace elements while high pH levels may facilitate the leaching of others such as Mo into the water (Brady, 1984). Low pH values may be as a result of the production of CO_2 from microbial respiration, which leads to the lowing of pH of the water (Pelig-Ba et al., 1991).

The EC of groundwater is its ability to conduct an electric current because of the presence of charged ionic species in solution. Conductivity values range between 102 and 1486 µS/cm with a mean and standard deviation of 452.2 and 287.9 µS/cm, respectively. One sample located at Tuna with a value of 1486 µS/cm exceeded the WHO (2003) permissible limit of 1400 µS/cm. Generally groundwater in the district has low conductivities implying low mineralization and may be termed as fresh water. Groundwater with low conductivities is suitable for irrigation.

To ascertain the suitability of groundwater for any purposes, it is essential to classify the groundwater depending upon their hydrochemical properties based on their TDS values (Catroll, 1962; Freeze and Cherry, 1979) which are presented in Table 4.2. According to the standard TDS classification (Fetter 1990), the groundwater falls under the category of fresh waters

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(TDS<1,000 mg/l). TDS concentration ranges from 42.3 to 740 mg/l with a mean and standard deviation of 238.8 and 148.6 mg/l respectively. The study shows that all the samples are below the WHO limit of 1000 mg/l, suggesting these samples can be used as drinking water without any health risk. 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).

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). The total hardness (TH) values range from 57.94 to 641.2 mg/l with an average value of 187.1 mg/l. (Table 4.1). The classification of groundwater based on TH (Table 4.3; Fig. 4.1) shows that approximately 64.4% of borehole water analysed recorded total hardness levels between 151 to 300 mg/l groundwater in the Sawla-Tuna-Kalba district could thus be classified as hard. Excess hardness is undesirable for aesthetic and economic reasons (Raghunath, 1987). Mean total hardness and alkalinity concentrations were 178 and 197 mg/L, respectively. This suggests that hardness of water is derived mainly from carbonate sources since the mean total alkalinity was slightly higher than that of total hardness. Groundwater with alkalinities higher than total hardness is mainly derived from carbonate sources. According to WHO (2004), a number of ecological and epidemiological studies have shown a significant inverse relationship between hardness of drinking water and cardiovascular diseases.

Table 4.2 Classifications of groundwater based on total dissolved solids (Fetter, 1990)

Total Dissolved Solids (mg/l)	Classification	Number of samples	Percentage
0 - 1000	Fresh water type	87	100
1000 - 10000	Brackish water type	0	0
10000 - 100000	Saline water type	0	0

Table 4.3 Classifications of groundwater based on total hardness (Fetter, 1990)

Total Hardness (mg/l)	Classification	Number of samples	Percentage
<75	Soft	6	6.9
75 - 150	Moderately Hard	25	28.7
150 - 300	Hard	46	52.9
>300	Very Hard	10	11.5

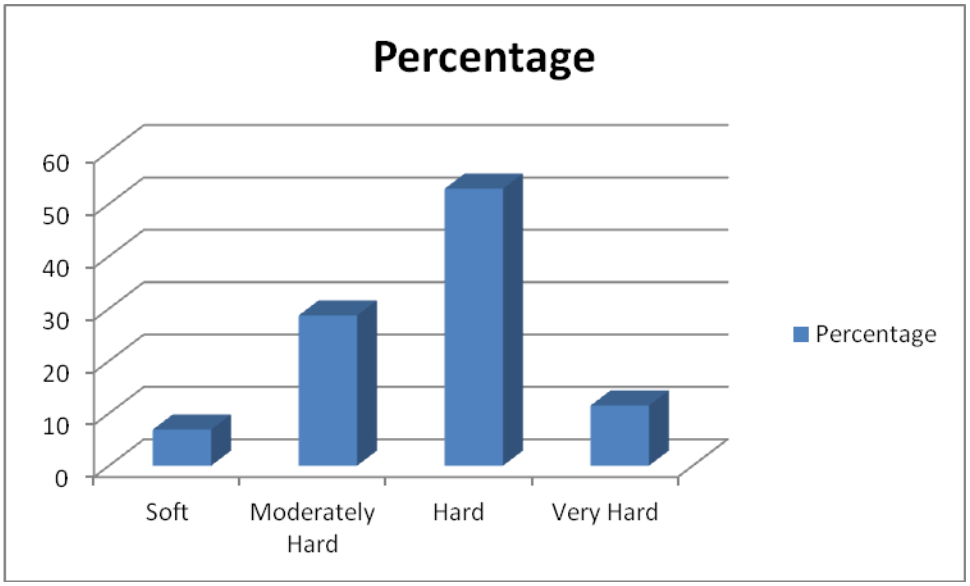

Fig 4.1 Percentage distribution of hardness in water samples from the study area

4.2 EFFECTS OF MAJOR IONS ON HEALTH

Major ions determined during the study are Mg^{2+}, Na^+, Ca^{2+}, K^+, HCO_3^- , Cl^- , F^- and SO_4^{2-}. From Table 4.1, the concentrations of major ions in borehole water were generally low and well below WHO recommended limit for potability. The presence of these ions in drinking water may not generally have harmful effects on humans; they may, however, present physiological or aesthetic problems to consumers.

Sodium is one of the common alkali metals in groundwater. The WHO (2004) maximum permissible concentration level of Na^+ in drinking water is 200 mg/l. Analysis of the results from the study area showed that the Na^+ concentration in the water samples ranged from 6.3 to 79.3 mg/l with a mean and standard deviation of 25.3 and 14.4 mg/l respectively (Table 4.1). All the groundwater samples had Na^+ concentrations well within the WHO (2004) standard as can be

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observed from (Fig. 4.2) which shows the distribution of sodium in the study area. Boreholes with sodium concentration 22.5 mg/l and below are found in the blue color zone numbering up to 41, those with sodium concentrations between 22.5-54.0 mg/l number up to 37 samples are located in the green zone and the yellow zones in the map is as a result of the two highest sodium concentrated boreholes.

The chloride ions occur in natural waters in fairly low concentrations, usually less than 10 mg/l unless the water is brackish or saline. Its concentration is extensively used as a tracer in groundwater studies because it is conservative (Freeze and Cherry, 1979; Fetter, 1992). Chloride in water samples from the study area range from 4 to 131 mg/l with an average and standard deviation of 19.5 and 23.0 mg/l respectively. All groundwater samples from the study area have chloride concentrations less than 150 mg/l and fall favorably within the WHO (2004) permissible limit of 250 mg/l as shown in (Fig. 4.3) which represents a percentage distribution of chloride ions in the water samples of the study area on a pie chart. High Na^+ and Cl^- levels above the WHO (2004) recommended guideline limits of 200 and 250 mg/L, respectively, would impart delectable taste to water while high SO_4^{2-} contents above 400 mg/L could have laxative effects in some people.

Fluoride ions in groundwater are mainly from natural sources and sometimes from the use of phosphate fertilizers (which contain 4% fluorine) (WHO, 2004). During the study fluoride ion concentration ranged from 0.1 to 1.9 mg/L with a mean of 0.6 mg/L. Fluoride levels were generally low, with the exception of Yilenteyiri (1.9 mg/L), which was above the recommended WHO guideline value of 1.5 mg/L. Fluoride in drinking water is important for health, in that it

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prevents tooth decay. However, high levels may lead to dental fluorosis. At elevated levels it may increase the rise of skeletal fluorosis. At higher concentrations fluoride is known to be poisonous and perhaps carcinogenic (Baird, 1999). The presence of fluoride in borehole water at these locations in the district gives cause for concern, especially given that high fluoride have been recorded in groundwater from some other areas in the region in previous studies (Apambire et al., 1997; Dey et al., 2004). Fluoride may possibly be derived from weathering of fluorapatite $[Ca_5(PO_4)_3F]$ in rock formations of the area.

High levels of nitrate in drinking water may cause methemoglobinemia in newborn infants under four years, as well as in adults with particular enzyme deficiency (Baird, 1999). Nitrate-N levels recorded in groundwater in the district ranged from 0.01 to 7.01 mg/L with a mean of 1.37 mg/L. All samples collected recorded nitrate-nitrogen levels below the WHO recommended limit of 10 mg/L. This suggests, no immediate threat to the health of infants in the community, from to nitrate-N pollution.

The potassium concentration in the groundwater ranges from 0.6 to 9.1 mg/l with a mean of 4.1 mg/l (Table 4.1). The WHO maximum permissible limit of potassium in drinking water is 30 mg/l. All samples can be seen to be within the WHO acceptable limit. The main sources of K^+ in groundwater have been extensively discussed (Fetter, 1994; Knobel and Phillips, 1998; Knobel et al., 1998), and include the dissolution of alkaline feldspars (microcline, orthoclase), micas (especially biotite) and glauconite. Other sources include the burning of fossil fuel and the use of compounds of inorganic fertilizers (NPK). Acute ingestion of doses of K^+ greater than 2.0

meq/kg body weight by people with normal kidney function could also, overwhelm homeostatic mechanisms and possibly cause death (Buckley et al., 1995).

The chemical results from the study area indicate that the Mg^{2+} concentrations generally range from 3.4 to 94.2 mg/l with a mean of 23.3 mg/l. Mg^{2+} concentrations in the groundwater samples from the area are generally extremely low, all the samples have concentrations below the WHO (year) acceptable limit of 150 mg/l. The main sources of Mg^{2+} in groundwater include the dissolution of dolomite (magnesian calcite) and dark coloured minerals such as the pyroxenes, amphibole and biotite (Chapelle, 1983; Fetter, 1994). The generally low magnesium concentrations in the area could be due to the fact that only limited sources of the ion exists in the area.

The Ca^{2+} concentrations in groundwater samples from the study are range from 8 to 131 mg/l with a mean of 36.7 mg/l. These Ca^{2+} concentrations are generally low and fall well within the WHO (year) maximum acceptable limit of 200mg/l. The common sources of Ca^{2+} in groundwater include the dissolution of carbonate minerals like calcite, aragonite and dolomite and the decomposition of sulphate, phosphate and silicate minerals

The SO_4^{2-} concentrations in the water samples range from 2.6 mg/l in Baaganda to 90.8 in Nakwabi with a mean and standard deviation of 12.2 and 13.3 mg/l respectively. Groundwater samples in the area are generally under saturated with sulphate. All groundwater samples have SO_4^{2-} concentrations below the WHO acceptable limit of 400 mg/l.

Chapelle (1983) studied the sources of sulphate in soils and groundwater and indicate that sulphate is commonly deposited on land surface by rainfall and some enters the groundwater system through recharge. Also, several soluble sedimentary minerals like gypsum ($CaSO_4.2H_2O$)

and anhydrite ($CaSO_4$) release SO_4^{2-} upon dissolution**.** The oxidation of metallic sulfides also contributes significant amounts of sulphate to groundwater systems.

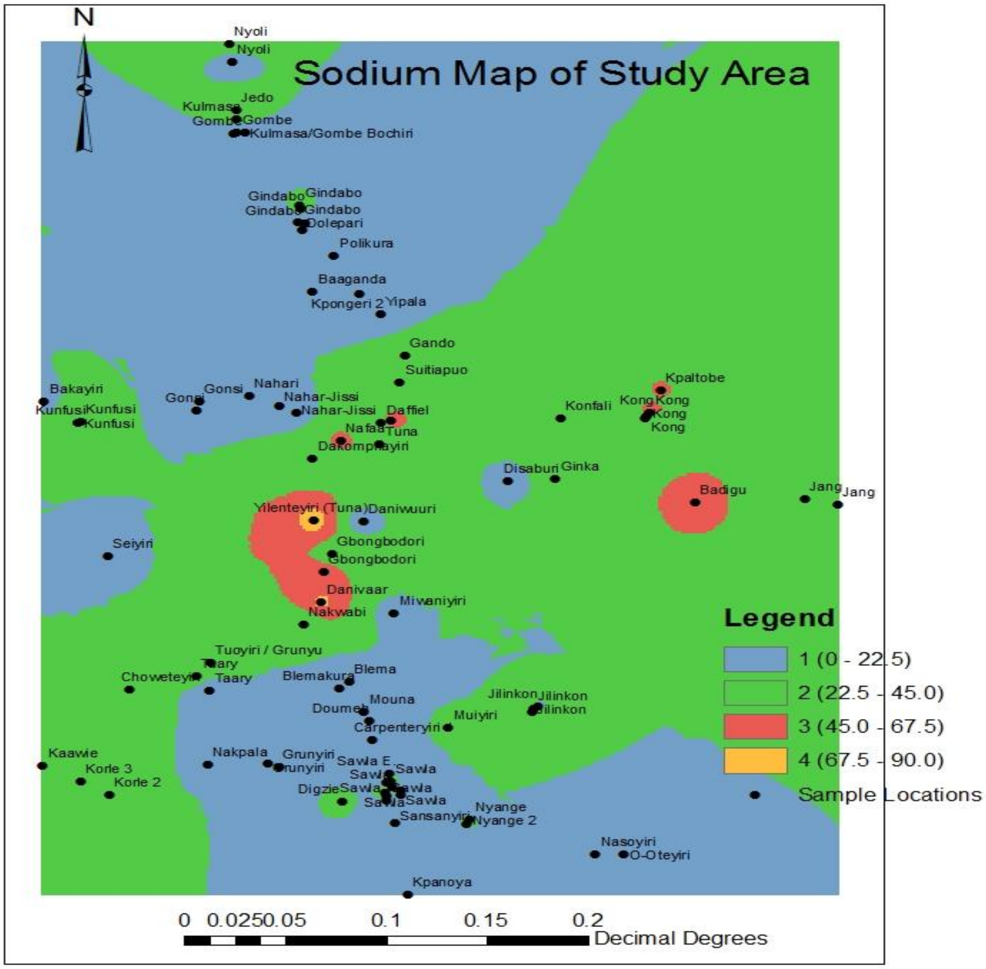

Fig. 4.2 Spatial distribution of sodium concentration in groundwater samples (mg/l)

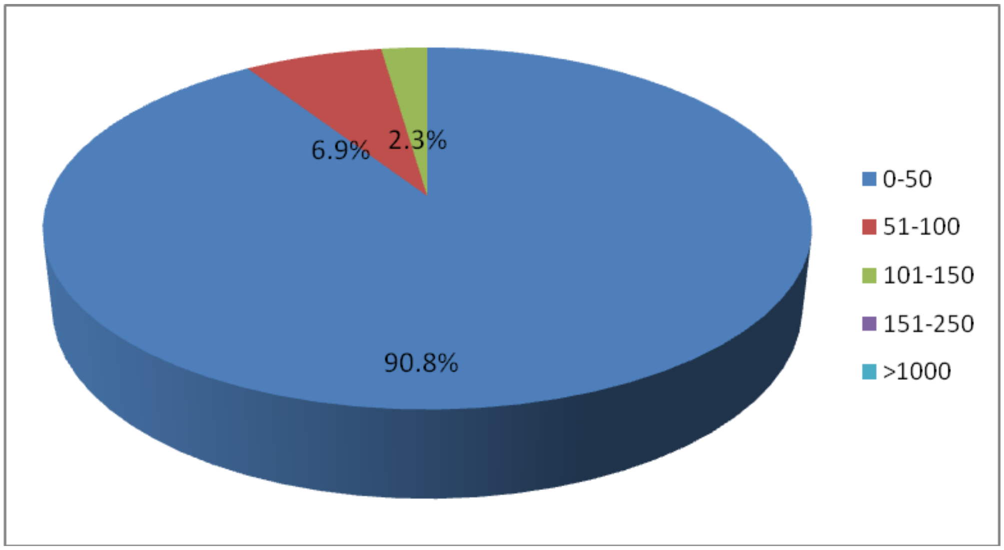

Fig 4.3. Pie-Chart showing the percentage distribution of chloride ion in water samples from the study area.

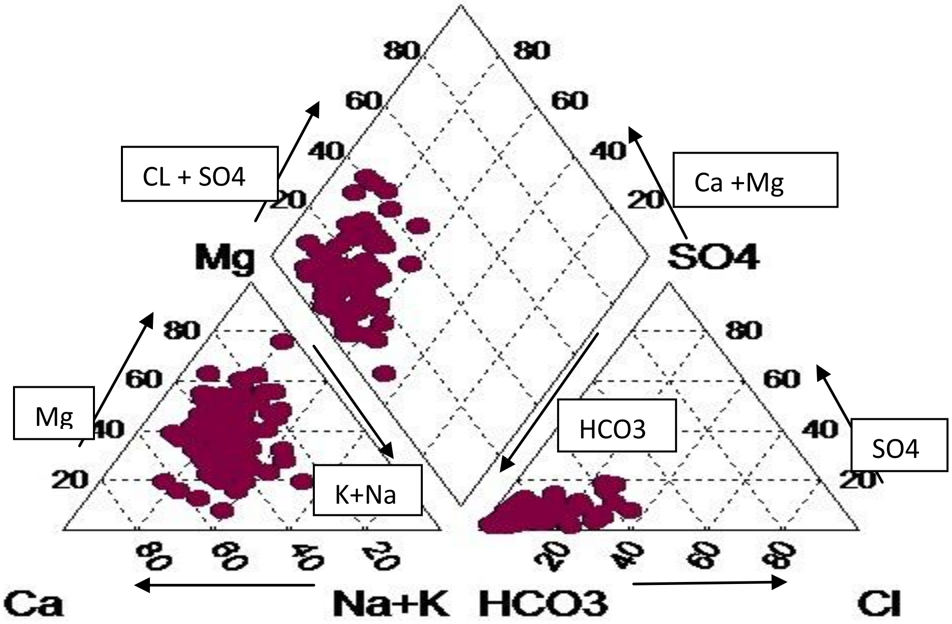

Fig 4.4: Piper diagram of groundwater samples from the Sawla Tuna Kalba District.

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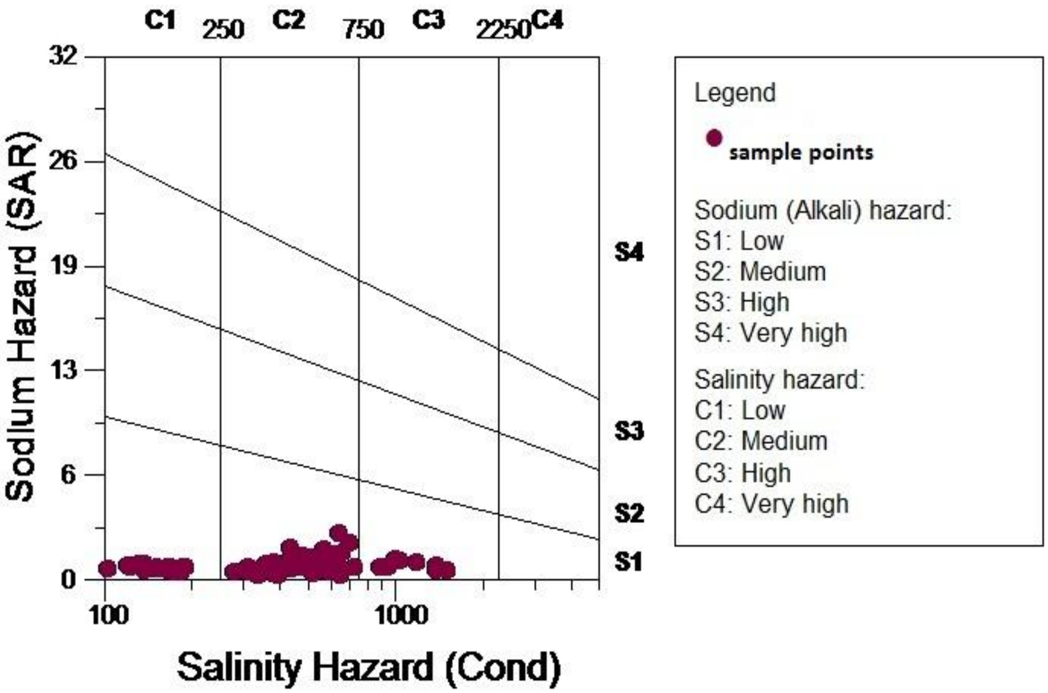

Fig. 4.5: US salinity diagram of groundwater in Sawla Tuna Kalba.

4.3 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 0.18-3.61 with a mean of 1.00±0.61 (Appendix 1). According to Richards (1954) classification based on SAR values, all samples belong to the excellent category (Table 4.4) implying that groundwater in the district could be harnessed for irrigation. This is true, provided essential nutrients like nitrogen and available phosphorus are not limiting in soils in the district.

Hydrochemical facies are distinct zones that possess cation and anion concentration categories (Sadashivaiah et al., 2008). Data for major ions in borehole water in the STK district are plotted on a Piper trilinear (Piper, 1994) diagram (Fig. 4.4) which is used for the determination of the hydrochemical nature of groundwater based on the dissolved major ions. It is evident from the results that groundwater in the study area falls in the Ca-Mg-HCO3 hydrochemical facies. This compares well with work done by Apambire et al. (1997) in other parts of northern Ghana.

Table 4.4: Classification of the analyzed groundwater on the basis of Na%, SAR, EC (Wilcox, 1995)

Parameter	Range	Water class	Samples
Na%	<20	Excellent	Nil
	20 – 40	Good	16
	40 – 60	Permissible	70
	60 – 80	Doubtful	1
	>80	Unsuitable	Nil
SAR	<10	Excellent	All (87)
	18	Good	Nil
	18 – 26	Doubtful	Nil
	>26	Unsuitable	Nil
EC	<250	Excellent	23
	250 – 750	Good	56
	750 – 2000	Permissible	8
	2000 – 3000	Doubtful	Nil
	>3000	Unsuitable	Nil

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4.3.1 Salinity Hazard

Excess salt increases the osmotic pressure of the soil solution that can result in a physiological drought condition. Even though the area may appear to have plenty of moisture, the plants wilt because insufficient water is absorbed by the roots to replace that lost from transpiration. The total soluble salt content of irrigation water generally is measured either by determining its electrical conductivity (EC), reported as micromhos per centimeter, or by determining the actual salt content in milliequivalent per litre. Tijani (1994) stated as reported by Aliou (2010) that irrigation water with an EC of <700 µS/cm causes little or no threat to most crops while EC>300 µS/cm may limit their growth.

The analytical data plotted on the US salinity diagram (Richards, 1954) illustrates that majority of the groundwater samples fall in the field of C2S1, indicating medium salinity and low sodium water, which can be used for irrigation on all types of soils without danger of exchangeable sodium (Fig. 4.5).

4.3.2 Alkali Hazard

Although sodium contributes directly to the total salinity the main problem with a high sodium concentration is its effect on the physical properties of soil. While high salt content (high EC) in water leads to formation of saline soil, irrigation with Na-enriched water results in ion exchange reactions: uptake of Na^+ and release of Ca^{2+} and Mg^{2+}. This causes soil aggregates to disperse, reducing its permeability (Tijani, 1994). The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed as the sodium adsorption ratio (SAR). The following formula is used to calculate SAR:

$$\text{SAR} = \frac{2\ \text{x}\ \text{Na}^{+}}{\sqrt{Ca2^{+} + Mg2^{+}}} \qquad 4.1$$

Ions in the equation are expressed in milliequivalent per liter. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soils. Continued use of water with a high SAR value leads to a breakdown in the physical structure of the soil caused by excessive amounts of colloidally absorbed sodium. This breakdown results in the dispersion of soil clay that causes the soil to become hard and compact when dry and increasingly impervious to water penetration due to dispersion and swelling when wet. Fine-textured soils, those high in clay, are especially subject to this action.

The calculated value of SAR of groundwater in the study area ranges from 0.175-2.753. As per the Richard (1954) classification based on SAR values (Table 4.4), 87 samples are in excellent category because none of the samples exceeded the value of SAR = 10 (Table 4.1).

4.3.3 Sodium Content

The sodium in irrigation waters is also expressed as percent sodium or soluble-sodium percentage (%Na) and can be determined using the following equation where all ionic concentrations are expressed in milliequivalents per liter. The values for the percent sodium in the study area range from 29.07 to 60.18%. It is observed that none of the samples in the area is within the excellent zone, 16 of the samples are good, 70 samples are within the permissible range and 1 sample is doubtful as shown in the (Table 4.4). High percentage of Na^{+} with respect to (Ca^{2+}+Mg^{2+}+Na^{+}) in irrigation water, causes deflocculating and impairing of soil permeability (Singh and Singh, 2008).

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4.3.4 Bicarbonate Hazard

High bicarbonate levels in groundwater according to McLean and Jankowiski (2000) can cause stunted growth in plants which can subsequently lead to calcite precipitation, decreasing soil permeability, lowering infiltration capacity and increasing erosion. The bicarbonate (HCO_3^-) ion is the principal alkaline constituent in almost all water supplies. Bicarbonate alkalinity is introduced into the water by CO_2 dissolving carbonate-containing minerals. Its alkalinity neutralizes the acidity in fruit flavours; and in the textile industry, it interferes with acid dying.

The presence of bicarbonates (HCO_3^-) influences the hardness and alkalinity of water. The inorganic carbon component (CO_2) arises from the atmosphere and biological respiration. The weathering of rocks contributes carbonate and bicarbonate salts.

In areas of non-carbonated rocks, the HCO_3^- and CO_3^{2-} originate entirely from the atmosphere and soil CO_2, whereas in areas of carbonate rocks, the rock itself contributes approximately fifty percent (50%) of the carbonate and bicarbonate present. Weathering of silicate minerals also acts as an important CO_2 sink (Chapman, 1992; Appelo and Postma, 1996).

The variation of hydrogen-carbonate in the study is within the range 61-515 mg/l and the mean and standard deviation are 232.1 mg/l and 98.6 mg/l respectively (Table 4.1). All of the wells had their values within the recommended levels of 1000 mg/l set by WHO (2004) on taste consideration.

According to Appelo and Postma (1996), bicarbonate ion concentration in groundwater could be derived from areas underlain by rocks composed of potassium feldspar, plagioclase feldspar or quartz.

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4.4 HYDRO-GEOCHEMICAL EVALUATION

The hydrogeochemical processes and hydrogeochemistry of the groundwater vary spatially and temporally, depending on the geology and chemical characteristics of the aquifer. An understanding of the geochemical evolution of groundwater is important for a sustainable development of water resources in the study area. The hydro-geochemical data subjected to various conventional graphical plots in order to identify the hydrogeochemical processes and mechanisms in the aquifer region of study area. All the possible identified processes are explained below in detail.

Chloroalkaline indices 1 and 2 (CAI 1 and CAI 2) that was calculated using equations 4.2 and 4.3, plotted in Fig. 4.6.

$$CAI1 = \frac{[Cl - (Na + K)]}{Cl} \tag{4.2}$$

$$CAI2 = \frac{[Cl - (Na + K)]}{(SO4 + HCO3 + CO3 + NO3)} \tag{4.3}$$

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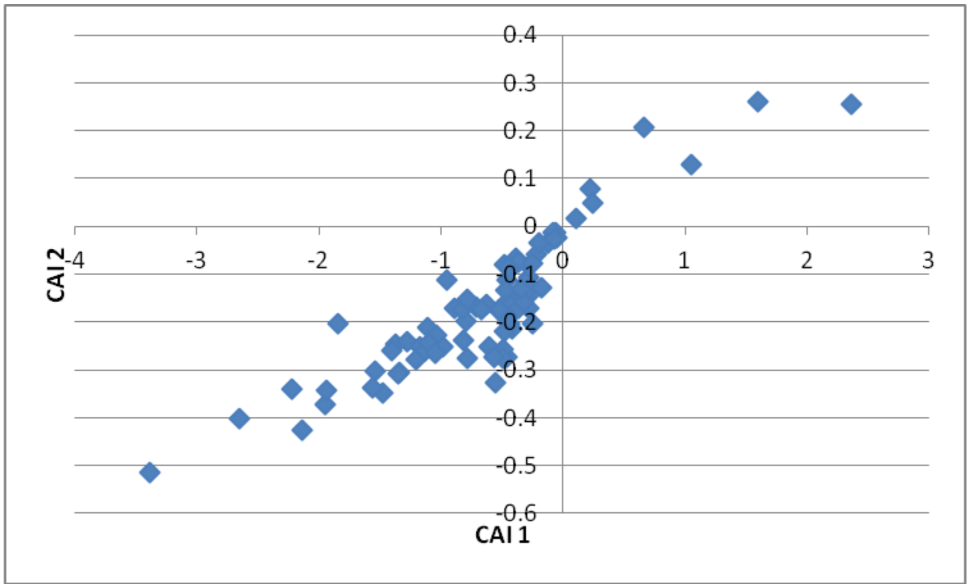

Fig 4.6 a plot of CAI 1 against CAI 2 the study area

The plot of Ca^{2+} + Mg^{2+} versus SO_4^{2-} + HCO_3^{-} will be closed to the 1:1 line if the dissolutions of calcite, dolomite and gypsum are the dominant reactions in a system. Ion exchange tends to shift the points to right due to an excess of SO_4^{2-} +HCO_3^{-} (Cerling et al. 1989; Fisher and Mulican 1997). If reverse ion exchange is the process, it will shift the points to the left due to a large excess of Ca^{2+} + Mg^{2+} over SO_4^{2-} + HCO_3^{-}.

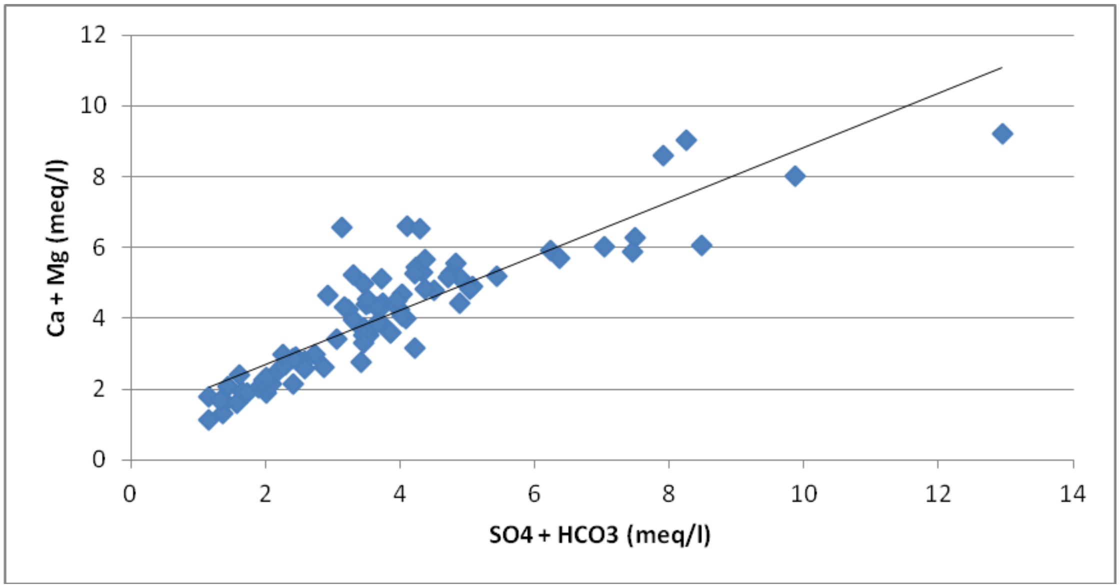

Figure 4.7 A scatter plot showing the relative roles of silicate mineral weathering and carbonate dissolution in the hydrochemistry

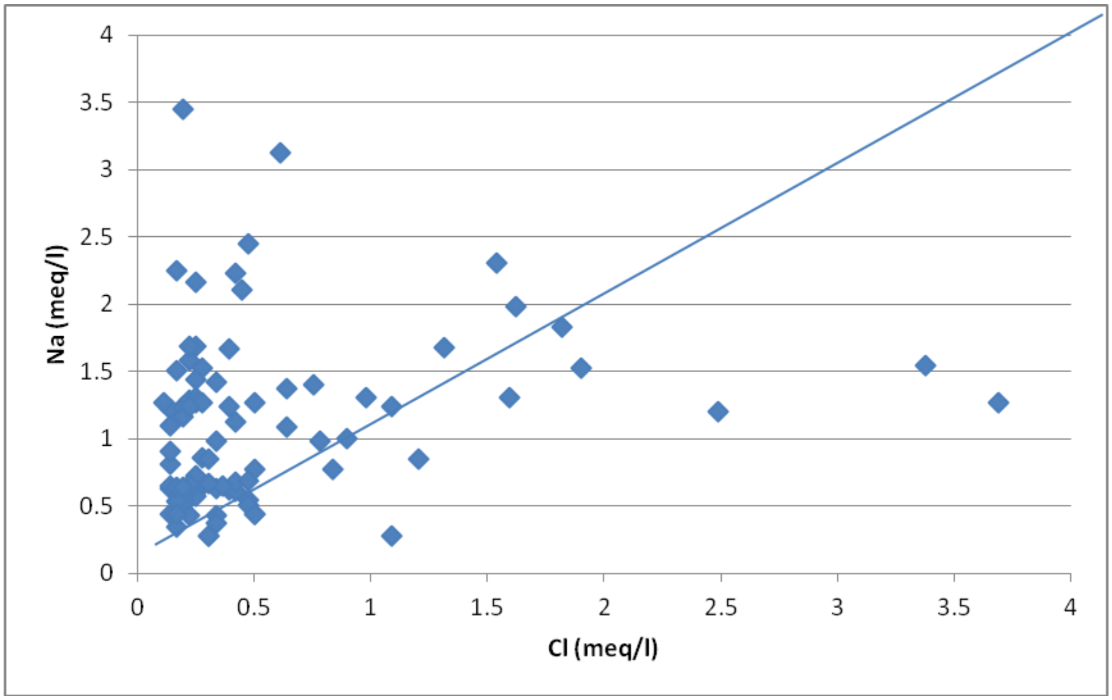

Figure 4.8: A scatter plot showing the relationship between the variations in the concentrations of sodium and chloride

Ca^{2+} + Mg^{2+} versus SO_4^{2-} + HCO_3^- (Fig. 4.7) shows that crystalline limestone, dolomitic limestone and kankar (the lime rich weathered mantle overlies carbonate rocks) are the major sources for carbonate in the area. The carbonates from these sources might have been dissolved and added to the groundwater system with recharging water during irrigation, rainfall or leaching and mixing processes. In Ca^{2+} + Mg^{2+} versus SO_4^{2-} + HCO_3^- scatter diagram (Fig. 4.7), the points falling along the equiline ($Ca^{2+} + Mg^{2+} = SO_4^{2-} + HCO_3^-$) suggests that these ions have been resulted from weathering of carbonates and silicates (Datta and Tyagi 1996; Rajmohan and Elango 2004; Kumar et al., 2006). Most of the data points, which fall in the Ca^{2+} + Mg^{2+} over SO_4^{2-} + HCO_3^- side, indicate that carbonate weathering is the dominant hydro-geochemical process, while those placed below the 1:1 line are indicative of silicate weathering.

In general, 1:1 relationship between Na and Cl implies halite dissolution, whereas increased concentration of Na than Cl is typically interpreted as Na released from silicate weathering (Mayback, 1987; Deutsch, 1997). In the study area considerable amount of groundwater samples are found above the 1:1 line in the Na vs. Cl scatter diagram (Fig. 4.8) indicates silicate weathering. Samples falling all along the 1:1 come from halite dissolution. But in the study area, the highest rainfall is experienced between July and September. The monthly average rainfall ranges between 200 and 300 mm, in this situation it is not possible for the availability of free halite for dissolution in the soil zone, but the irrigation activities in the study area might have increased the concentration of Na in groundwater.

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CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATION

5.1 CONCLUSIONS

The source of most of the hydro-geochemical parameters in the water in the area is dissolution from the rocks as the water percolates underground. However, percolation and geochemical processes such as dissolution/precipitation, ion exchange processes, oxidation and reduction, within the groundwater system also account for some of the parameters. Groundwater plays a vital role in the supply of fresh water for both domestic and agricultural purposes in rural communities of the Sawla Tuna Kalba Districts. Interpretation of hydrochemical analysis reveals that groundwater in the study area is fresh and hard according to the WHO guidelines. Ca-Mg-HCO_3 type of hydrochemical facies was identified as the major groundwater type in the study area using piper trilinear diagram and is excellent for agricultural purposes due to the low SAR values of (0.175-2.70) recorded.

The abundance of the major ions in the area is as follows: $Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$ and $HCO_3^{-}>Cl^{-}>SO_4^{2-}>NO_3^{-}$. Analytical data plot on the US Salinity diagram also illustrated that majority of groundwater samples fall in the field of C2S1; indicating medium salinity and low sodium water. In the study area considerable amount of groundwater samples are found above the 1:1 line in the Na vs. Cl scatter diagram, indicating silicate weathering. Samples' falling all along the 1:1 comes from halite dissolution.

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Key findings in the current study

I. The SAR calculated for all groundwater samples in the district ranged from 0.18-3.61 with a mean of 1.00±0.61 (Appendix 1). According to Richards (1954) classification based on SAR values, all samples belong to the excellent category, implying that groundwater in the district could be harnessed for irrigation.

II. Data for major ions in borehole water in the STK district were plotted on a Piper trilinear diagram which was used for the determination of the hydrochemical nature of groundwater based on the dissolved major ions. It is evident from the results that groundwater in the study area falls in the Ca-Mg-HCO3 hydrochemical facies.

III. The concentrations of major ions in borehole water were generally low and well below WHO recommended limit for potability. The presence of these ions in drinking water may not generally have harmful effects on humans

IV. The classification of groundwater based on TH shows that approximately 64.4% of borehole water analysed recorded total hardness levels between 151 to 300 mg/l groundwater in the Sawla-Tuna-Kalba district could therefore be classified as hard.

V. The source of most of the hydro-geochemical parameters in the water in the area is dissolution from the rocks as the water percolates underground

5.2 RECOMMENDATIONS

i. Groundwater quality in the study area should be monitored regularly to ensure early detection and intervention of any pollution or contamination that may occur due to the susceptibility of the regional aquifer system to pollution (weedicides, pesticides etc.).

ii. Further research should be conducted to estimate the safe yield in order to know the volume of water that can be abstracted and readily available for irrigation and its sustainability.

iii. Drilled wells that are not in use should be capped to protect the water from being contaminated by anthropogenic activities in the area.

iv. Ghana now has a national water policy, which is underpinned by the principles in the Ghana Poverty Reduction Strategy, the Millennium Development Goals and the "Africa Water Vision" of the New Partnership for Africa's Development (NEPAD). The policy gives direction for sustainable development, management and use of water resources in the country. The Water Resources Commission, under the Water Directorate of the Ministry of Water Resources, Works and Housing, has the overall responsibility of the water sector of Ghana. The regulation and 44 management of Ghana's water resources including groundwater is guided by the Water Resources Commission (WRC) Act, (No. 522 of 1996) and the Water Use Regulations Legislative Instrument (LI 1692 of 2001). The granting of water use permit is considered a tool to regulate water abstraction and control pollution of water bodies in Ghana.

v. Since the groundwater in the area is suitable for irrigation purposes, it is recommended that irrigation facility be given to the area for dry season farming to supplement food production and create employment for the youth.

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APPENDICES

Appendix 1. Water quality parameters for irrigation purposes

COMMUNITY	SAR	Na%	COMMUNITY	SAR	Na%	COMMUNITY	SAR	Na%
Baaganda	0.715	50.70	Nakwabi	0.542	35.04	Sawla	0.672	47.99
Daniwuuri	0.313	37.66	Seiyiri	0.313	37.66	Sawla	0.764	39.05
Dolepari	0.421	43.20	Taary	0.374	39.89	Sawla	0.398	39.79
Gindabo	0.175	42.10	Taary	0.859	41.83	Kpanoya	0.747	44.53
Gindabo	0.192	33.17	Tuoyiri / Grunyu	0.903	46.74	Badigu	1.533	48.33
Gindabo	0.909	44.34	Carpenteryiri 1	0.258	40.80	Daffiel	1.861	52.49
Gindabo	0.898	47.27	Digzie	0.844	44.76	Daffiel	0.900	49.87
Gombe	0.630	43.55	Doumeh	0.281	36.93	Dakompilayiri	1.128	45.70
Gombe	0.430	29.29	Grunyiri	0.539	47.61	Disaburi	0.605	48.06
Jedo	1.154	42.43	Grunyiri	0.700	44.55	Gando	0.936	42.99
Kpongeri 2	0.501	42.98	Jilinkon	0.676	40.66	Ginka	0.880	47.61
Kulmasa	1.018	45.35	Jilinkon	0.483	44.08	Gonsi	0.650	50.15
Kulmasa/Gombe	0.594	33.29	Jilinkon	0.695	44.38	Gonsi	0.822	53.32
Nyoli	1.014	48.24	Korle 2	1.392	41.11	Jang	1.031	39.51
Nyoli	0.712	43.82	Korle 3	0.832	47.56	Jang	0.731	43.23
Polikura	0.632	50.14	Mouna	0.233	41.38	Konfali	1.231	42.25
Bakayiri	0.572	47.97	Muiyiri	0.793	47.83	Kong	1.145	49.16
Kunfusi	0.946	54.36	Nakpala	0.649	38.05	Kong	0.695	37.44
Kunfusi	0.959	50.75	Nasoyiri	0.688	42.86	Kong	1.158	40.78
Kunfusi	0.610	42.99	Nyange	0.655	40.94	Kong	1.038	42.22
Yilenteyiri (Tuna)	2.753	60.18	Nyange 2	0.619	43.85	Kpaltobe	1.364	48.90
Blema	0.876	53.12	O-Oteyiri	0.810	43.64	Nafaa	1.466	54.96
Blemakura	0.455	41.68	Sansanyiri	0.499	47.71	Nahari	0.670	46.54
Choweteyiri	1.024	45.15	Sawla	0.722	43.85	Nahar-Jissi	0.658	51.68
Danivaar	2.182	55.82	Sawla	1.085	45.35	Nahar-Jissi	0.413	37.10
Gbongbodori	1.733	55.05	Sawla E.	0.887	48.48	Suitiapuo	0.968	46.07
Gbongbodori	1.185	53.36	Sawla W.	1.038	46.49	Tuna	0.497	41.31
Kaawie	0.613	42.21	Sawla	0.919	44.32	Tuna	0.749	29.07
Miwaniyiri	0.622	45.84	Sawla	0.672	38.91	Yipala	0.606	39.84

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Appendix 2. Water quality results

Community	EC. µS/cm	pH (6.5-8.5)	Tot. Alkal.	Ca+ (mg/l)	Mg+ (mg/l)	Na+ (mg/l)	K+ (mg/l)	HCO3- (mg/l)	SO4- (mg/l)	Cl- (mg/l)	NO3-(N)(mg/l)	F (mg/l)	TDS(mg/l)	TH(mg/l)
Baaganda	122	6.48	80.0	11.2	10.2	13.8	4.4	97.6	2.6	8.9	2.35	0.2	61.0	69.82
Daniwuuri	516	7.10	150	39.3	22.8	10.0	7.7	183	27.8	17.9	1.72	0.5	259	191.73
Dolepari	277	6.60	122	19.2	14.6	10.1	5.5	149	3.7	5.0	0.13	0.3	139	107.86
Gindabo	393	6.89	208	32.1	39.3	6.3	3.7	254	12.5	10.9	0.21	0.7	201	241.38
Gindabo	640	6.61	126	48.1	21.8	6.4	6.0	154	30.5	38.7	0.98	0.6	320	209.63
Gindabo	427	6.91	216	40.1	20.9	28.6	2.0	264	4.0	7.0	<0.01	0.6	214	185.94
Gindabo	431	6.90	214	32.1	25.2	28.1	2.1	261	4.1	5.0	<0.01	0.7	216	183.57
Gombe	158	6.75	104	22.4	11.6	14.8	1.8	127	3.5	8.9	0.22	0.3	79.3	103.56
Gombe	183	6.22	90.0	32.1	4.8	9.9	6.5	110	3.5	11.9	1.41	0.2	91.4	99.93
Jedo	546	7.06	208	48.9	12.6	35.1	3.7	254	10.4	9.9	<0.01	1.0	273	173.91
Kpongeri 2	321	9.81	136	24.1	16.5	13.1	4.5	166	3.8	8.9	0.48	0.3	161	127.9
Kulmasa	500	7.26	260	48.1	29.1	36.4	0.6	317	17.6	7.9	0.10	1.1	250	239.56
Kulmasa/Gombe Bochiri	102	6.22	86.0	27.3	3.4	12.4	6.0	105	9.8	7.0	0.04	0.5	51.4	82.19
Nyoli	624	7.01	222	40.9	40.8	38.5	2.2	271	35.1	46.7	0.54	1.2	314	269.53
Nyoli	164	6.09	52.0	16.0	4.4	12.5	7.0	63.4	3.6	16.9	6.13	0.1	81.9	58.04
Polikura	379	6.87	190	16.8	34.5	19.8	2.0	232	3.6	9.9	0.42	0.4	189	183.45
Bakayiri	362	6.84	196	22.4	34.5	18.6	1.9	239	15.0	5.0	0.04	0.5	180	197.45
Kunfusi	1175	6.80	276	8.0	85.0	42.1	2.9	337	35.4	64.5	1.49	0.6	591	368.5
Kunfusi	531	6.75	178	24.9	34.0	31.5	2.5	217	21.3	22.8	0.92	0.7	266	201.65
Kunfusi	138	6.98	50.0	16.8	6.3	11.6	5.9	61.0	15.5	16.9	5.03	<0.01	68.8	67.83
Yilenteyiri (Tuna)	633	7.45	318	36.9	15.5	79.3	5.4	389	9.8	7.0	0.14	1.9	317	155.8
Blema	130	6.56	92.0	12.0	15.5	19.6	0.7	112	8.9	10.9	2.51	0.5	64.9	93.55

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Appendix 2. Water quality results (continue)

Community	EC. µS/cm	pH (6.5-8.5)	Tot. Alkal.	Ca+ (mg/l)	Mg+ (mg/l)	Na+ (mg/l)	K+ (mg/l)	HCO3- (mg/l)	SO4- (mg/l)	Cl- (mg/l)	NO3-(N)(mg/l)	F (mg/l)	TDS(mg/l)	TH(mg/l)
Blemakura	334	6.89	140	24.1	15.0	11.6	6.0	171	4.9	7.0	<0.01	0.6	168	121.75
Choweteyiri	545	7.06	164	36.1	15.0	29.1	2.3	200	6.5	17.9	2.50	0.5	273	151.75
Danivaar	689	7.46	322	40.9	24.7	71.9	5.6	393	7.2	21.8	<0.01	1.3	346	203.52
Gbongbodori	560	7.36	256	29.7	21.8	51.2	5.6	312	5.9	14.9	<0.01	1.3	280	163.63
Gbongbodori	431	6.97	208	20.8	26.2	34.6	5.7	254	3.9	6.0	<0.01	1.0	215	159.42
Kaawie	638	7.54	276	55.3	41.7	24.9	1.5	337	19.5	22.8	3.04	0.6	319	309.22
Miwaniyiri	150	6.50	110	18.4	12.6	14.2	3.5	134	3.4	13.9	<0.01	0.4	75.2	97.66
Nakwabi	1368	7.60	306	115	49.4	27.7	9.1	373	90.8	88.3	3.09	1.1	682	490.04
Seiyiri	516	7.10	150	39.3	22.8	10.0	7.7	183	27.8	17.9	1.72	0.5	259	191.73
Taary	584	7.08	200	37.7	25.7	12.2	3.7	244	3.2	6.0	<0.01	0.8	292	199.62
Taary	525	7.22	260	49.7	22.3	29.1	4.9	317	4.1	4.0	0.77	1.0	262	215.68
Tuoyiri / Grunyu	432	7.05	210	33.7	24.3	28.3	1.6	256	4.3	7.0	0.01	1.1	216	183.88
Carpenteryiri 1	329	6.70	172	28.9	25.2	7.9	4.4	210	3.5	6.0	<0.01	0.5	168	175.57
Digzie	358	8.10	188	34.5	19.4	25.1	1.4	229	7.1	5.0	0.34	0.9	178	165.79
Doumeh	377	6.71	184	36.1	19.9	8.5	7.2	224	3.2	11.9	<0.01	0.4	189	171.84
Grunyiri	165	6.65	132	17.6	22.3	14.5	1.4	161	15.9	5.0	0.30	0.6	82.8	135.43
Grunyiri	188	6.52	102	24.9	14.1	17.7	4.7	124	5.2	29.8	0.92	0.4	94.1	120.06
Jilinkon	874	6.67	276	73.0	45.6	30.0	2.5	337	16.9	34.7	2.99	0.4	436	369.46
Jilinkon	652	7.10	236	36.9	38.8	17.7	6.1	288	9.3	17.9	0.51	0.7	326	251.33
Jilinkon	719	7.27	258	50.5	46.1	28.5	1.9	315	25.6	38.7	7.01	0.5	359	315.26
Korle 2	478	7.09	228	51.3	4.3	38.7	5.0	278	3.8	8.9	<0.01	1.0	239	145.88
Korle 3	487	7.21	258	34.5	36.4	29.5	1.9	315	4.6	7.9	0.09	0.9	245	235.49
Mouna	335	6.70	126	22.4	20.9	6.4	3.8	154	3.7	10.9	0.07	0.2	167	141.69

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Appendix 2. Water quality results (continue)

Community	EC. µS/cm	pH (6.5-8.5)	Tot. Alkal.	Ca+ (mg/l)	Mg+ (mg/l)	Na+ (mg/l)	K+ (mg/l)	HCO3- (mg/l)	SO4- (mg/l)	Cl- (mg/l)	NO3-(N)(mg/l)	F (mg/l)	TDS(mg/l)	TH(mg/l)
Muiyiri	482	7.21	252	32.9	38.8	28.5	1.5	307	5.6	13.9	0.15	0.6	244	241.33
Nakpala	497	6.34	118	43.3	15.0	19.5	5.3	144	19.8	42.7	1.01	0.6	249	169.75
Nasoyiri	168	6.38	76.0	20.0	6.8	14.0	3.5	92.7	3.9	14.9	1.93	0.2	83.8	77.88
Nyange	477	7.10	226	47.3	25.7	22.6	7.2	276	12.3	11.9	<0.01	0.6	239	223.62
Nyange 2	436	6.91	210	41.7	35.4	22.6	6.5	256	31.1	27.8	0.03	0.4	218	249.39
O-Oteyiri	120	6.42	82.0	17.6	3.4	14.2	3.7	100	6.5	7.9	0.14	0.1	60.2	57.94
Sansanyiri	136	6.56	168	19.2	30.1	15.1	1.3	205	7.9	7.9	0.71	0.5	67.6	171.41
Sawla	150	7.38	106	20.0	7.3	14.9	3.9	129	14.3	5.0	0.46	0.4	75.2	79.93
Sawla	465	7.01	214	40.9	17.9	33.2	6.3	261	6.5	8.9	<0.01	0.7	232	175.64
Sawla E.	137	6.54	80.0	16.0	6.3	16.6	3.4	97.6	3.6	8.9	1.96	0.5	68.3	65.83
Sawla W.	456	6.86	188	37.7	21.3	32.3	1.0	229	6.6	26.8	0.67	0.5	227	181.58
Sawla	461	6.91	230	42.5	22.8	30.0	4.8	281	3.9	8.9	0.02	0.6	231	199.73
Sawla	309	6.35	98.0	28.1	7.3	15.5	4.3	120	8.0	14.9	0.72	0.4	155	100.18
Sawla	123	6.21	90.0	15.2	11.7	14.4	4.9	110	5.0	11.9	2.90	0.3	615	85.97
Sawla	466	6.42	150	44.9	14.5	23.1	5.7	183	15.5	31.8	1.05	0.4	233	171.7
Sawla	307	6.68	130	24.1	13.1	9.8	3.1	159	3.9	7.9	<0.01	0.2	154	113.96
Kpanoya	135	6.50	100	18.4	6.3	14.6	4.0	122	3.7	6.0	<0.01	0.3	67.7	71.83
Badigu	648	7.20	322	50.5	21.3	51.7	5.5	393	4.8	6.0	0.01	1.3	325	213.58
Daffiel	430	7.00	230	41.7	16.5	56.3	6.4	281	18.4	16.9	1.20	1.1	216	171.9
Daffiel	444	7.14	222	25.7	32.0	29.1	0.7	271	3.6	8.9	0.18	0.7	222	195.45
Dakompilayiri	457	7.30	196	38.5	15.0	32.7	4.5	239	18.9	11.9	0.06	0.4	229	157.75
Disaburi	172	6.63	126	17.6	20.4	15.8	3.7	154	3.2	16.9	0.04	0.1	86.2	127.64
Gando	459	7.08	196	43.3	17.9	29.1	5.5	239	19.5	9.9	0.67	0.8	230	181.64

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Community	EC. µS/cm	pH (6.5-8.5)	Tot. Alkal.	Ca+ (mg/l)	Mg+ (mg/l)	Na+ (mg/l)	K+ (mg/l)	HCO3- (mg/l)	SO4- (mg/l)	Cl- (mg/l)	NO3-(N)(mg/l)	F (mg/l)	TDS(mg/l)	TH(mg/l)
Ginka	448	7.20	224	29.7	24.3	26.8	5.1	273	3.0	7.0	0.04	0.5	224	173.88
Gonsi	122	6.41	90.0	12.8	16.5	15.0	1.5	110	9.2	12.9	5.03	0.4	61.2	99.65
Gonsi	137	6.77	140	11.2	22.3	20.8	1.0	171	3.2	5.0	0.32	0.7	68.5	119.43
Jang	516	7.41	230	60.9	16.0	35.1	5.3	281	9.8	67.5	0.08	1.1	258	217.85
Jang	531	7.15	234	44.9	29.6	25.8	3.2	285	23.8	14.9	<0.01	1.1	266	233.61
Konfali	505	7.51	252	53.7	12.6	38.7	3.2	307	3.8	7.9	<0.01	1.3	253	185.91
Kong	555	7.21	268	36.1	29.1	38.3	5.2	327	3.2	13.9	0.01	0.6	278	209.56
Kong	929	7.17	260	82.6	34.9	30.0	7.2	317	38.9	56.6	6.13	0.5	465	349.59
Kong	990	7.23	412	95.4	37.8	53.0	7.5	503	16.5	54.6	4.24	0.8	495	393.48
Kong	1027	7.27	406	86.6	47.0	48.5	7.2	495	43.2	15.9	1.62	0.7	513	409.2
Kpaltobe	561	7.26	260	43.3	24.7	45.6	3.7	317	3.2	57.6	<0.01	0.5	281	209.52
Nafaa	613	7.43	278	24.1	37.9	49.8	1.1	339	5.4	8.9	0.28	1.0	307	215.64
Nahari	185	6.46	104	18.4	12.6	15.3	4.7	127	4.8	10.9	0.68	0.5	92.5	97.66
Nahar-Jissi	84.8	6.45	112	10.4	18.0	15.2	1.0	137	3.3	7.9	5.58	0.3	42.3	99.8
Nahar-Jissi	171	6.59	128	27.3	10.7	10.1	2.9	156	4.5	6.0	<0.01	0.4	85.6	112.12
Suitiapuo	380	6.60	172	34.5	18.9	28.6	1.2	210	25.1	7.9	0.32	0.3	191	163.74
Tuna	1486	7.01	422	102	94.2	29.1	2.4	515	36.9	131	2.03	1.2	740	641.22
Tuna	1362	6.84	268	131	23.2	35.5	9.3	327	33.9	120	2.03	1.0	682	422.62
Yipala	317	6.85	146	28.1	10.2	14.8	2.9	178	3.6	7.0	<0.01	0.3	159	112.07