# EVALUATION OF THE QUALITY OF WATER FROM BOREHOLES SELECTED FROM THE EJISU-JUABEN AND BOSOMTWI-ATWIMA-KWANWOMA DISTRICTS OF THE ASHANTI REGION OF GHANA

By

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I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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## DEDICATION

This thesis is dedicated to my parents Mr. Joseph Bright Nkansah and Mrs. Mary Nkansah who gave up all that they could become so that I could be all that I have become.

Thanks Dad and Mum. God bless.

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## ABSTRACT

In this project, the quality of water from 21 boreholes from 13 communities in the Ejisu-Juaben (E-J) and 17 boreholes from 11 communities in the Bosomtwi-Atwima-Kwanwoma Districts (BAK) of the Ashanti Region of Ghana has been determined within the period of November 2004 to June 2005.

Water samples were analysed for the following parameters: sampling temperature, pH, colour , conductivity, total dissolved solids, turbidity, alkalinity, hardness some selected anions ($SO_4^{2-}$, $Cl^-$, $PO_4^{3-}$ and $NO_2^-$) and some heavy metals (Fe, Mn, Cu, Zn, Cd, Pb, K and Na).

The UV-Visible Spectrophotometer was used to determine $SO_4^{2-}$ by the barium precipitation method, $PO_4^{3-}$ by the ascorbic acid method, $NO_2^-$ by sulphanilic acid method and humic substances by direct determination.

Atomic Absorption Spectrophotometer was used to determine Fe, Mn, Cu, Zn, Cd, Pb; tritrimetry was employed to measure alkalinity, hardness and chloride content. Sodium and Potassium concentrations were determined with Flame Photometry.

The results were compared to WHO standards and were observed that determinations were all within the limits with the exception of samples AC3, AC2 and AC1 from Achiase and PS of Paakoso all in the E-J district gave very low pH values of 3.95, 4.25, 4.26 and 4.63 respectively.

There were some isolated cases of contamination by cadmium of 0.006mg/L at Bowohommoden and Brahabebome.

Further contamination by Lead of 0.029mg/L in sample AD1 from Adumasa and 0.0215mg/L from Bowohommoden (all from the E-J district) were also observed.

High levels of colour at 60 HU and 40 HU were observed for samples OD1 and OD2 from Kokodee and ASS1 from Asisiriwa all in the BAK district.

In addition, high levels of turbidity of 7.48 for samples TA1 from Toamfom and 44.95 NTU for sample ASS1 from Asisiriwa were observed. Samples OD1 and OD2 from Kokodee also gave high turbidities of 20.2 NTU and 12.68 NTU respectively. All these occurred in the BAK district.

The results showed that water from the boreholes in the two districts had acceptable quality to allow its application in household activities.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| **AAS** | Atomic Absorption Spectrophotometer |
| **ACS** | American Chemical Society |
| **BAK** | Bosomtwi-Atwima-Kwanwoma |
| **E-J** | Ejisu-Juaben |
| **FES** | Flame Emission Spectroscopy |
| **CWSA** | Community Water and Sanitation Agency |
| **USEPA** | United States Environmental Protection Agency |
| **UNICEF** | United Nations Children's Emergency Fund |
| **GWCL** | Ghana Water Company Limited |
| **WHO** | World Health Organisation |
| **TDS** | Total Dissolved Solids |
| **GPRS** | Ghana Poverty Reduction Strategy |
| **CSIR** | Council for Scientific and Industrial Research |
| **APHA** | American Public Health Association |
| **EPA** | Environmental Protection Agency |
| **USGS** | United States Geological Survey |

# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1.0 Background

Our earth seems to be unique among the other known celestial bodies. This is because it has water which covers three-fourths of its surface and constitutes 60-70 wt % of the living world [ACS, 1994].

Water regenerates and is redistributed through evaporation, making it seem endlessly renewable.

Actually, only 1% of the world's water is usable to us as fresh water. About 97% is salty seawater, and 2% is frozen in glaciers and polar ice caps. Thus, only 1% of the world's water supply is a precious commodity necessary for our survival [Pestle *et al.*, 1997].

### 1.1.1 The hydrologic cycle

From the time the earth was formed, terrestrial moisture is in constant motion and all near-surface water participates in what is called the hydrologic cycle. The term 'cycle' suggests that water comes from a source and ultimately returns to a source. Groundwater is part of this continuous cycle as water evaporates, forms clouds and returns to the earth as precipitates [Fetter, 1994].

The hydrologic cycle goes through a process of evaporation, condensation, precipitation, deposition, runoff, infiltration, sublimation, transpiration, melting and ground water flow.

The process is powered by solar energy.

The process commences when surface water is evaporated from the earth surface by the energy from the sun. The vapour is lifted up by convection, orographic and cyclonic mechanism into the sky resulting in cooling and formation of clouds in the sky. Depending on the temperature and weather conditions, the water vapour condenses and falls to the earth as different types of precipitates.

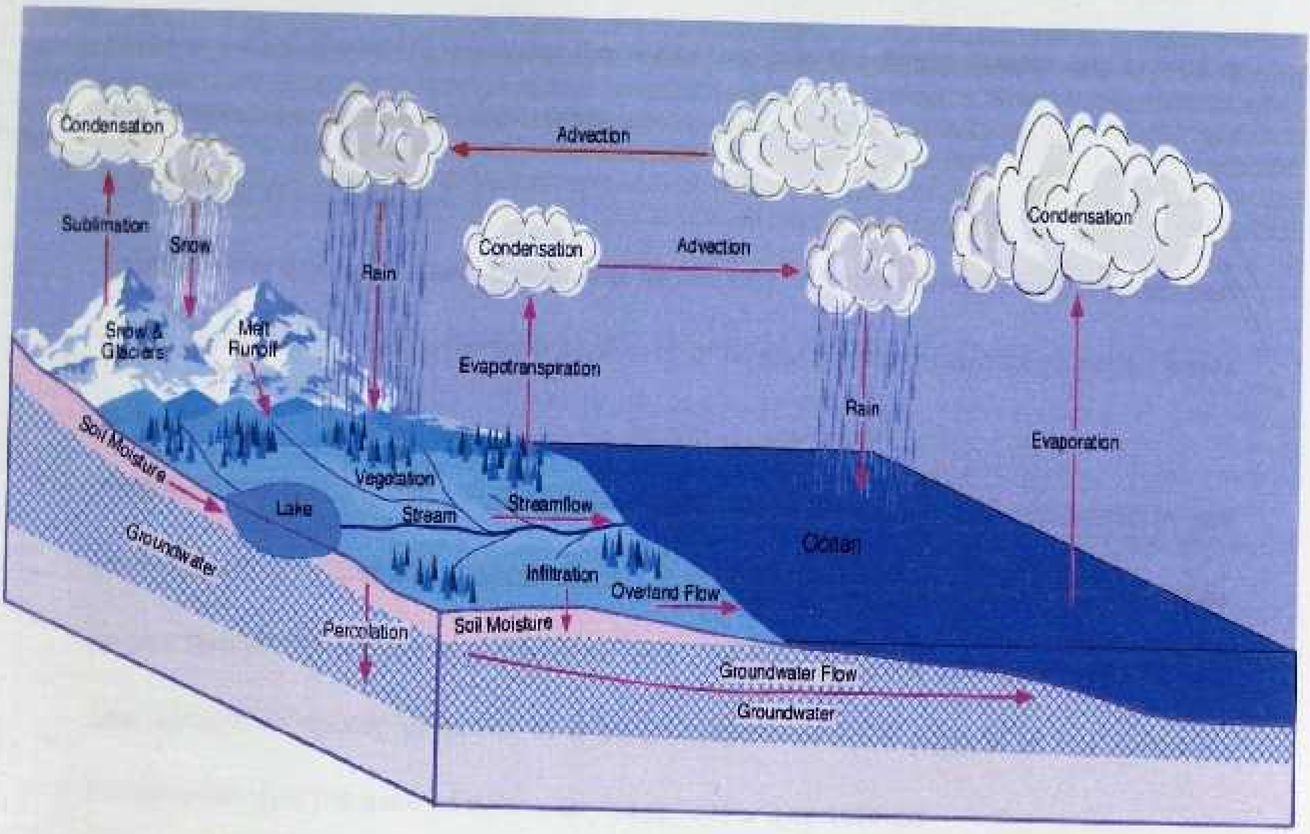


**Fig. 1.1 Schematic diagram of the hydrologic cycle**

**Source**: Martin Chaplain, February 2004,http://www.lsbu.ac.uk/water/data.html.

### 1.1.2 How does water get into the ground?

When rain falls to the ground, the water does not stop moving. Some of it flows along the land surface to streams or lakes, some is used by plants, some evaporates and returns to the atmosphere, and some seeps into the ground. Water seeps into the ground much like a glass of water poured onto a pile of sand [Clark *et al.*, 1993].

As water seeps into the ground, some of it clings to particles of soil or to roots of plants just below the land surface. This moisture provides plants with the water they need to grow. Water not used by plants moves deeper into the ground. The water moves downward through empty spaces or cracks in the soil, sand, or rocks until it reaches a layer of rock through which water cannot easily move. The water then fills the empty spaces and cracks above that layer. The top of the water in the soil, sand, or rocks is called the water table and the water that fills the empty spaces and cracks is called groundwater [Clark *et al.*, 1993]

### 1.1.3 What is an aquifer?

Groundwater occurs in many geological formations. Almost all rocks in the upper part of the earth's crust, whatever their type, origin or age possesses openings called pores or voids.

Aquifer is the name given to underground soil or rock through which groundwater can easily move. The amount of groundwater that can flow through soil or rock depends on the size of the spaces in the soil or rock and how well the spaces are connected. The amount of spaces or pores in a given volume of rock particle is the *porosity*. Permeability is a measure of how well the spaces are connected.

Aquifers typically consist of gravel, sand, sandstone or fractured rock such as limestone. These types of materials are permeable because they have large connected spaces that allow water to flow through. The spaces in a gravel aquifer are called *pores*. The spaces in a fractured rock aquifer are called *fractures*. If a material contains pores that are not connected, groundwater cannot move from one space to another. These materials are said to be impermeable. Materials such as clay or shale have many small pores, but the pores are not well connected. Therefore, clay or shale usually restricts the flow of groundwater [Birdie *et al.*, 2002].

### 1.1.4 Groundwater flow and permeability

Some geological materials such as clay have high porosity and low specific yield meaning that little of the water in their pores can move .The ability of rock or sediment to transmit water through its pores is called its *permeability* [Merritis *et al.*, 1998].

High permeable materials include well sorted coarse sand and gravel as well as crystalline rocks such as granite, with extensive fractures while those with low permeability include crystalline rocks with few or no fractures and very poorly sorted sediments [Merritis et al 1998].

Since permeability determines the rate at which water and pollutants flow through rocks and sediments it is a major concern in the setting of facilities for hazardous and radioactive wastes.

The greatest danger involved in storing radioactive or hazardous wastes underground is the risk of the contamination leaking into the surrounding host rock or sediment and ultimately into the underground water [Merritis *et al.*, 1998].

### 1.1.5 Can groundwater be finished or overexploited?

We can run out of ground water if more water is discharged than recharged. For example, during periods of dry weather, recharge to the aquifers decreases. If too much ground water is pumped during these times the water table can fall and wells may go dry [Merritis *et al.*, 1998].

### 1.1.6 Groundwater levels

Changes in water levels in wells reflect changes in recharge to, and discharge from an aquifer. Recharge rates vary in response to precipitation, evaporation, transpiration by plants and surface-water infiltration into an aquifer. Discharge occurs as natural flow from an aquifer to streams or springs, as evaporation and transpiration from the shallow water table, as leakage to vertically adjacent aquifers, and as withdrawal from wells. Where water-level changes are due to withdrawals, they also may reflect changes in groundwater flow direction.

## 1.2 Statement of the Problem

According to the global environment outlook, about 20% of the world's population lack access to safe drinking water, while 50% has no access to safe sanitation system. Globally, one-third of the water available consists of groundwater that is more or less accessible. It is on record that in 1995, consumption of water reached 23000$cm^3$, most of which went to agriculture, industry and domestic use [UNEP, 2000]. Additionally, the demand for fresh water as of now has more than doubled relative to that of immediate past years. This fact notwithstanding the proportion of available but polluted water continuously increases particularly because of changes in the modes of industrial and agricultural production and increasing urbanization [Pestle *et al.*, 1997].

The image of Africa is sharply focused in the centre of this water crisis. A world population report on "Population Growth and Water Supplies: an emerging crisis" stipulates that currently, over 200 million Africans live in water-stressed or water-scarce countries and Ghana is no exception [UNEP, 2000].

By the year 2025, the number will rise to about 700 million of whom over half will live in countries that face severe water shortage for most part of the year [Pestle *et al.*, 1997].

Notwithstanding this gloomy picture about global water supply, it is sad to note that the rather scarce water available is also polluted in one way or the other.

On a global scale, 25,000 people die each day as a result of poor water quality. Water-related diseases, such as cholera, diarrhoea, Guinea worm, filariasis, malaria, river blindness, bilharzias, sleeping sickness and typhoid still represent the single largest cause of human morbidity and mortality. At the beginning of the 21st century some 1.1 billion people around the world lacked access to clean drinking water and 2.4 billion had no sanitation.

These figures are outrageous especially in Africa and Asia and life expectancy is very low [Myers, 2004].

Until the 1970s, many of Bangladesh's people became sick from drinking polluted water drawn from surface rivers. Aid agencies such as the United Nations Children's Emergency Fund (UNICEF) built shallow wells throughout the country that provided a seemingly safe source of water for Bangladesh's poor. In the 1990's, however, it was discovered that many of these wells were contaminated by arsenic, a poison that occurs naturally in Bangladesh's alluvial soils [Lepkowski, 1998].

In the United States of America where ground water is important in all climatic conditions, it accounts for about 50% of livestock and irrigation water use and just 37% of public water supplies. In the rural areas however, 96% of public water is supplied from ground water where people supply their own drinking water from domestic wells [UNESCO, WHO & UNEP, 1996].

In Latin America many of the continent's largest cities Mexico City, Lima, Buenos Aires and Santiago obtain a significant proportion of their municipal water supply from groundwater [UNESCO, WHO & UNEP, 1996].

According to a survey conducted by UNEP in 1989 most of the countries in Europe depend on groundwater. Groundwater forms 98%, 94%, 89% and 88% of drinking water supplies for Denmark, Portugal, Germany, Italy and Switzerland respectively among others [Prairie, 2000].

In Africa and Asia most of the major cities rely on surface water but many millions of people in the rural areas are dependent on ground water [Prairie, 2000].

In Ghana, improper handling of pesticides, fertilizers and other chemicals used in farming, industry and household activities close to water sources are known to influence the levels of contaminants in the water table.

The people of Ejisu-Juaben District who are predominantly farmers use a wide range of chemicals in their activities. Activities like washing also occur around the pumps which are a likely source of contamination as a result of ions like phosphate, sodium, potassium etc. that might be found in soap.

The situation at Bosomtwi-Atwima-Kwanwoma is not any different from that of Ejisu-Juaben.

Even though groundwater is generally less contaminated than surface waters, pollution of this major water supply has become an increasing concern in industrialized nations. Many thousands of wells have been closed since the late 20th century because of contamination by various toxic substances [Lepkowski, 1998].

The overall goal of a ground water assessment programme is to obtain a comprehensive picture of the spatial distribution of groundwater quality and of the changes in time that occur either natural or under the influence of man.

Ground water seems the best source free from contamination but could be unsafe.

## 1.3 Research Questions

1. Is water from boreholes in the Ejisu-Juaben and the Bosomtwi-Atwima-Kwanwoma districts of Ashanti of good quality?
2. What are the levels of trace metals and nutrients in the borehole water from the districts?
3. Is the organic acid content of borehole water of any relevance in determining its quality?
4. Are there any correlations between the indicators of quality?

## 1.4 Objectives

- The overall objective of this project was to assess the quality of water from boreholes in the Ejisu-Juaben and Bosomtwi-Atwima-Kwanwoma districts of the Ashanti Region of Ghana.

The determination of the following parameters as indices of quality constituted the specific objectives of the study:

- pH, total dissolved solids, conductivity, alkalinity, hardness, sulphate, nitrite, phosphate, colour, turbidity, chloride, sodium, potassium, lead, manganese, iron, zinc, cadmium, copper and organic acid concentration.
- An additional objective was to make recommendations to all stakeholders.

## 1.5 Justification of the Project

Many African governments including that of Ghana have anticipated some of the problems outlined above and have adopted a number of policies to be implemented over a period of time to help address the imbalance in the water economy.

Among them is the vision 2020 document, which outlines strategies to improve water supply to the rural communities by the year 2020. Also in support to this move is the

Ghana Poverty Reduction Strategy (GPRS) for the period 2002-2004, which stipulates that 54% of the rural population and 78% of urban population should have access to safe water by the year 2004 [GPRS ,2002-2004].

However, the attention on water supply had been chemical treatment of rivers and streams until the demand for fresh water increased rapidly as population exploded and became more urban. It became increasingly difficult to draw on these sources for optimum supply. This is because the cost of water per capita increased with increasing prices of chemicals, power and technology.

It is in this regard that there was an urgent need to look for an alternative, reliable and safe source of water supply that will be accessible and relatively affordable to support the hitherto traditional sources.

The government of Ghana has therefore resorted to borehole water as one of the alternatives. Through the work of the World Vision, Rural Water Project of the Community Water and Sanitation Agency, the Water Resources Institute (CSIR) and many other institutions hundreds of boreholes are constructed annually [Issah, 2000].

The Community Water and Sanitation Agency in collaboration with Ghana and donor agencies has been involved in the construction of boreholes in mostly rural areas in Ghana. The Ejisu-Juaben and Bosomtwi-Atwima-Kwanwoma districts have enjoyed this facility. The people believe this new source of water is better in quality than the traditional rivers and streams they know.

It is therefore imperative to assess the quality of borehole water, which is a readily available source and virtually free to the people of the two districts

This work seeks to use basically physicochemical parameters as the indices of water quality.

Appropriate recommendations of suitable purification methods will be made depending on the outcome of the assessment.

Scientific explanation must be offered to the piles of data of analyzed water samples in order to gain insight into the mechanisms of the inflows and outflows of water in the catchments areas of boreholes.

The need for scientific analysis motivates the rational for this analysis.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1.0 Determinants or indicators of water quality

The indicators of water quality are generally categorised into Physico-chemical and biological factors.

### 2.1.1 Physico-chemical Parameters

Some of the Physico-chemical parameters of interest are:

### 2.1.2 pH

The pH of a solution is a measure of the acidic nature of that solution. The concentration of the hydrogen ion $[H^+]$ activity in a solution determines the pH. Mathematically this is expressed as:

$pH = -\log[H^+]$

Pure water at 25°C contains equal amounts of hydroxyl and hydroxonium ions. Natural waters often have a pH of 4 to 9 and most are slightly basic as a result of the presence of bicarbonates and carbonates of the alkali and alkaline earth metals.

**Principle**: The determination of pH involves the activity of hydrogen ions by potentiometric measurement using a standard hydrogen electrode and a reference electrode. This is the underlying principle of electrometric pH measurement.

The hydrogen electrode consists of a platinum electrode across which hydrogen gas is bubbled at a pressure of 101Kpa. Due to the difficulty in the use of this method, the glass electrode is usually used in pH measurements. The pH meter is normally calibrated potentiometrically with an indicator glass electrode and a reference electrode using buffers.

Measurements of pH are influenced by temperature in two ways: mechanical effects caused by changes in the properties of the electrode and chemical effects caused by equilibrium changes.

In the former, the Nernstian slope increases with increasing temperature and takes a lot of time for electrodes to attain thermal stability. This can cause a long term drift in the pH. Due to the effect of chemical equilibrium on pH, standard pH buffers have a specific pH at a specified temperature [APHA, 1985].

### 2.1.3 Conductivity

Conductivity is defined as the ability of a solution to carry electric current. This is normally dependent on the presence of ions, their total concentration, mobility, valence, relative concentration and temperature of measurement. Compounds which dissociate easily in solution are good conductors while those which do not dissociate easily are poor conductors. Inorganic acids, bases and salts are good conductors while organic compounds are poor conductors. In a laboratory determination, conductivity is measured as resistance measured in ohms. The conductivity of fresh distilled water is in the range of 0.5 -2.0µmhos/cm.The conductivity of portable water is generally in the range of 50-1500µmhos/cm. The conductivity of industrial waste is 10,000µmhos/cm.

**Principle**: (Laboratory conductivity experiments are used to):

a) Establish degree of mineralization, to assess the effect of the total concentration of ions on chemical equilibria, physiological effects on living things and the rate of corrosion.

b) To assess the degree of mineralization of distilled water and deionised water.

c) To check the results of a chemical analysis and estimate the sample size to be used for simple chemical determinations.

d) Determine the amount of ionic reagent needed in the precipitation and neutralisation reactions. The end point of such reactions is normally determined by plotting a graph of conductivity versus burette readings.

e) When conductivity is multiplied by a factor, total dissolved solids of water can be determined. This factor may vary from 0.55 to 0.9 depending on the soluble components of the water and on the temperature of measurement.

f) To assess the changes in dissolved mineral concentration of raw or waste waster as far as seasonal variations are concerned.

Electrolytic conductivity unlike metallic conductivity increases with temperature at a rate of about 1.9%/C.

Inaccurate temperature readings can lead to errors. Potassium chloride has a lower temperature coefficient of conductivity than typical potable water. Sodium chloride however has a temperature coefficient that is very close to that of most ground and surface waters [APHA, 1985]

### 2.1.4 Total dissolved solids (TDS)

Source - Total Dissolved Solids (TDS) consist mainly of carbonates, bicarbonates, chlorides, sulphates, phosphates, nitrates, calcium, magnesium, sodium, potassium, iron, manganese and a few others. They do not include gases, colloids or sediment. The TDS can be estimated by measuring the specific conductance of the water. Dissolved solids in natural waters range from less than 10 mg/l for rain to more than 100,000 mg/l for brines. Since TDS is the sum of all materials dissolved in the water, it has many different mineral sources. Below is an indication of the TDS from various

Sources: Distilled Water-0, Two-column Deionizer Water-8, Rain and Snow-10, Brine Well-125,000 and Dead Sea-250,000.

High levels of total dissolved solids can adversely affect industrial applications requiring the use of water such as cooling tower operations, boiler feed water, food and beverage industries and electronics manufacturers. High levels of chloride and sulphate will accelerate corrosion of metals. The USEPA has a suggested level of 500 mg/l listed in the Secondary Drinking Water Standards.

**Principle**: Gravimetrically, a well mixed volume of sample is evaporated in a weighed dish and dried to constant weight in an oven at 103 -105°C.The increase in weight over that of the empty dish is the total solids. The value may not necessarily represent the actual suspended and dissolved solids. This is due to interference from highly mineralised water with significant concentrations of calcium, magnesium etc which may be hygroscopic and require excessive, proper desiccation and rapid weighing.

A standard glass fibre filter is used to filter a well mixed sample and the filtrate is evaporated to dryness in a weighed dish to constant weight at 180°C.

Total dissolved solids can also be determined by using an electronic probe which also measures temperature and conductivity [APHA, 1992].

### 2.1.5 Temperature

Temperature is the measure of how hot or cold water is. This is measured with a thermometer in either degree Celsius or degree Fahrenheit [APHA, 1985].

### 2.1.6 Hardness

The hardness of a water supply is determined by the content of calcium and magnesium salts. Calcium and magnesium combine with bicarbonates, sulphates, chlorides and nitrates to form these salts. The standard domestic measurement for hardness is grains per gallon (gpg) as $CaCO_3$. Water having a hardness content less than 0.6 gpg is considered commercially soft. The calcium and magnesium salts which form hardness are divided into two categories: Temporary Hardness (containing carbonates) and Permanent Hardness (containing non-carbonates). A more elaborate definition of the forms of hardness is given below.

**Temporary Hardness Salts**

Calcium Carbonate ($CaCO_3$) - Known as limestone, rare in water supplies causes alkalinity in water. Calcium Bicarbonate [$Ca(HCO_3)_2$] forms when water containing $CO_2$ comes in contact with limestone which also causes alkalinity in water. When heated $CO_2$ is released and the calcium bicarbonate reverts back to calcium carbonate, forming scales.

Magnesium Carbonate ($MgCO_3$) Known as magnetite with properties similar to calcium carbonate. Magnesium Bicarbonate [$Mg(HCO_3)_2$] is also similar to calcium bicarbonate in its properties.

**Permanent Hardness Salts**

Calcium Sulphate ($CaSO_4$) - Know as gypsum, used to make plaster of Paris. Will precipitate and form scale in boilers when concentrated. Calcium Chloride ($CaCl_2$) reacts in boiler water to produce a low pH as follows:

$$CaCl_2 + 2HOH \Longrightarrow Ca(OH)_2 + 2HCl$$

Magnesium Sulphate ($MgSO_4$) - Commonly known as Epsom salts, may have laxative effect if great enough quantity is in the water. Magnesium Chloride ($MgCl_2$) is similar in properties to calcium chloride.

Sodium salts are also found in household water supplies, but they are considered harmless as long as they do not exist in large quantities [Casiday *et al.*, 1998].

**Principle**: Ethylenediaminetetraacetic acid and its sodium salt form a chelate soluble complex in solution of certain metal ions. The addition of small amounts of dye such as Erichrome Black-T or calmagite to an aqueous solution containing calcium and magnesium at pH 10±1will result in a red wine coloured solution indicating the end point. When EDTA is used as the titrant, calcium and magnesium ions will be complexed and the red wine colour appears after all such ions have been complexed. Magnesium ion must be present to yield a satisfactory end point [APHA, 1992].

### 2.1.7 Alkalinity

Alkalinity may be defined as the ability of water to neutralise an acid, and is determined by titration against a known standard acid (usually 0.02 N sulfuric acid). Alkalinity has traditionally been reported in terms of mg/L as $CaCO_3$. This is somewhat a confusing nomenclature since the chemical species responsible for virtually all the alkalinity of natural waters is the bicarbonate ion ($HCO_3^-$).

The optimal amount of alkalinity for a given water is a function of several factors including pH, hardness and the concentrations of dissolved oxygen and carbon dioxide that may be present. As a general rule, 30 to 100 mg/L as $CaCO_3$ is desirable although up to 500 mg/L may be acceptable.

Alkalinity is apparently unrelated to public health (at least directly), but is very important in pH control. Alum, gaseous chlorine and other chemicals occasionally used in water treatment act as acids and therefore tend to depress pH. Alkalinity resists this change and thereby provides buffer capacity. Many waters are deficient in natural alkalinity and must be supplemented with lime (CaO or $Ca(OH)_2$ or some other chemical to maintain the pH in the desirable range (usually 6.5 to 8.5).

Alkalinity values can change significantly for groundwater between samples taken at the wellhead and samples taken from other spots [USEPA, 1994].

**Principle (Titration Method)**: Hydroxyl ions are present in a sample as a result of dissociation.

Alkalinity is generally expressed as phenolphthalein alkalinity corresponding to titration with acid to the pH at which $HCO_3^-$ is the predominant carbonate species (pH 8.3) or total alkalinity, corresponding to titration with acid to the methyl orange end point (pH 4.3) where both carbonate species have been converted to $CO_2$.

Alkalinity is generally expressed in mg/L of $CaCO_3$ based upon the following neutralising reaction:

$$CaCO_3 + 2H^+ \longrightarrow Ca^{2+} + CO_2 + H_2O$$

Each $CO_3$ ion neutralises two $H^+$ ions [Manahan, 1994].

### 2.1.8 Chloride

Source - Chloride ($Cl^-$) is one of the major anions found in water and is generally combined with calcium, magnesium or sodium. Since almost all chloride salts are highly soluble in water, the chloride content ranges from 10 to 100 mg/l. Sea water contains over 30,000 mg/l as NaCl. Chloride is associated with the corrosion of piping because of the compounds formed with it. For example, magnesium chloride can generate hydrochloric acid when heated. Corrosion rates and the iron dissolved into the water from piping increases as the sodium chloride content of the water is increased. The chloride ion is instrumental in breaking down passivating films which protect ferrous metals and alloys from corrosion and is one of the main causes for the pitting corrosion of stainless steel. The SMCL (suggested maximum contaminant level) for chloride is 250 mg/l which is due strictly to the objectionable salty taste produced in drinking water [USEPA, 1994].

### 2.1.9 Sulphate

Source-Sulphate ($SO_4$) occurs in almost all natural water. Most sulphate compounds originate from the oxidation of sulphite ores, the presence of shale and the existence of industrial wastes. Sulphate is one of the major dissolved constituents in rain.

As water moves through soil and rock formations that contain sulphate minerals, some of the sulphate dissolves into the groundwater. Minerals that contain sulphate include magnesium sulphate (Epsom salt), sodium sulphate (Glauber's salt) and calcium sulphate (gypsum).

High concentrations of sulphate in drinking water cause a laxative effect when combined with calcium and magnesium, the two most common components of hardness. Bacteria which attack and reduce sulphates cause hydrogen sulphide gas ($H_2S$) to form. Sulphate has a suggested level of 250 mg/l in the secondary Drinking Water Standards published by the USEPA.

**Principle**: Sulphate ($SO_4^{2-}$) ion is precipitated in an acetic acid medium with barium chloride to form barium sulphate. Light absorbance of barium sulphate suspension by a UV- visible spectrophotometer at 420nm is used to determine the sulphate concentration. This was done by comparison with the calibration curve [APHA, 1985].

### 2.1.10 Phosphate

Phosphorus is one of the key elements necessary for growth of plants and animals. Phosphorus in elemental form is very toxic and is subject to bioaccumulation. Phosphates $PO_4^{3-}$ are formed from this element. Phosphates exist in three forms: orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate. Each compound contains phosphorous in a different chemical formula. Ortho forms are produced by natural processes and are found in sewage. Poly forms are used for treating boiler waters and in detergents. In water, they change into the ortho form. Organic phosphates are important in nature. Their occurrence may result from the breakdown of organic pesticides which contain phosphates. They may exist in solution as particles, loose fragments or in the bodies of aquatic organisms. Rainfall can cause varying amounts of phosphates to wash from farm soils into nearby waterways. Phosphate will stimulate the growth of plankton and aquatic plants which provide food for fish.

Phosphate also leaches into underground water. It may not be toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphate [USGS, 1970].

### 2.1.11 Colour

Source - Colour in water is almost always due to organic material which is usually extracted from decaying vegetation. Colour is common in surface water supplies, while it is virtually non-existent in spring water and deep wells. Colour in water may also be the result of natural metallic ions (iron and manganese). A yellow tint to the water indicates that humic acids are present, referred to as "tannins". A reddish colour would indicate the presence of precipitated iron. Stains on bathroom fixtures and on laundry are often associated with colour also. Reddish-brown is ferric hydroxide (iron) will precipitate when the water is exposed to air. Dark brown to black stains are created by manganese. Excess copper can create blue stains.

**Principle**: The observed colour of water is the result of light back scattered upward from the water after it has passed through to various depths and undergone selective absorption. Colour and turbidity determine the depth to which light penetrates in water systems. In water, the light intensity or irradiance at a particular depth (**$I_z$**) is a function of the intensity at the surface (**$I_o$**) to the exponent of the negative extinction coefficient at the depth distance **z** which is called the Beer-Lambert's Law. $I_z = I_o e^{-az}$ [Freifelder, 1985].

The visible colour in a water sample is the light that is refracted, reflected or re-emitted by substances in water because it has not been absorbed to produce heat or chemical reactions.

True colour is due to natural minerals such as ferric hydroxide and dissolved organic substances such as humic or fulvic acids.

Colour measured in water containing suspended matter is defined as apparent colour [APHA, 1992].

The Colour of water measured by Colorimetric methods is based on the calibration of absorbance of the water sample at a variety of single wavelengths, usually against the Pt-Co standard.

Standard measurement comparisons can be made with sealed containers.

Natural waters range from <5 mg/L Pt in very clear waters to 1200 mg/L Pt in dark peaty waters [Keyser, 1997]

### 2.1.12 Nitrite

Source - Nitrites are not usually found in drinking water supplies at concentrations above 1 or 2 mg/l (ppm). Nitrates are reduced to nitrites in the saliva of the mouth and upper gastro intestinal (GI) tract. This occurs to a much greater degree in infants than in adults because of the higher alkaline conditions in their GI tract. The nitrite then oxidises haemoglobin in the blood stream to methemoglobin, thus limiting the ability of the blood to carry oxygen throughout the body. Anoxia (an insufficiency of oxygen) and death can occur. The US EPA has established the MCL (maximum contaminant level) for nitrite at 1 mg/l. [Alloway *et al.*, 1997].

**Principle**: Nitrite ion in a suitable medium is diazotised with sulphanilamide resulting into a diazo compound .This in turn is coupled with N (-1-naphtyl) ethylene-diamine to form a highly coloured azo dye [APHA, 1985].

### 2.1.13 Nitrate

Source - Nitrate ($NO_3$) comes into water supplies through the nitrogen cycle rather than via dissolved minerals. It is one of the major ions in natural waters. Most nitrates that occur in drinking water are as a result of contamination of groundwater supplies by septic systems, feed lots and agricultural fertilizers. Nitrate is reduced to nitrite in the body.

Treatment - Reverse Osmosis will remove 92 - 95% of the nitrates and or nitrites. Anion exchange resin will also remove both as will distillation [Alloway *et al.*, 1997].

### 2.1.14 Turbidity

Source -Turbidity is the term given to anything that is suspended in a water supply. It is found in most surface waters, but usually doesn't exist in groundwater except in shallow wells and springs after heavy rains. Turbidity gives the water a cloudy appearance or shows up as dirty sediment. Undissolved materials such as sand, clay, silt or suspended iron contribute to turbidity. Turbidity can cause the staining of sinks and fixtures as well as the discolouring of fabrics. Usually turbidity is measured in NTUs (nephelometric turbidity units). Typical drinking water will have a turbidity level of 0 to 1 NTU. Turbidity can also be measured in ppm (parts per million) and its size is measured in microns. Turbidity can be particles in the water consisting of finely divided solids, larger than molecules, but not visible by the naked eye, ranging in size from 0.001 to 0.150 mm (1 to 150 microns).

Treatment-Typically turbidity can be reduced to 75 microns with a cyclone separator, then reduced down to 20 micron with standard back washable filter, however flow rates of 5 gpm / sq. ft. are recommended maximum. Turbidity can be reduced to 10 micron with a multimedia filter while providing flow rates of 15 gpm/sq. ft. Cartridge filters of various sizes are also available down into the submicron range [USEPA, 1994].

**Principle**: Turbidity of water is caused by suspended matter such as clay, silts, finely divided organic and inorganic matter, soluble coloured organic compounds and plankton and other microscopic organisms.

Turbidity expresses the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the samples. Correlation of turbidity with weight concentration of suspended matter is difficult because the size, shape and refractive index of the particulates also affect the light scattering properties of the suspension [APHA, 1985]

### 2.1.15 Iron

Iron is one of the most troublesome elements in water supplies. Making up at least 5 percent of the earth's crust, iron is one of the earth's most plentiful resources. Rainwater as it infiltrates the soil and underlying geologic formations dissolves iron, causing it to seep into aquifers that serve as sources of groundwater for wells. Although present in drinking water, iron is seldom found at concentrations greater than 10 milligrams per liter (mg/l) or 10 parts per million. However, as little as 0.3 mg/l can cause water to turn a reddish brown colour.

Iron is mainly present in water in two forms; either the soluble ferrous iron or the insoluble ferric iron. Water containing ferrous iron is clear and colourless because the iron is completely dissolved. When exposed to air in the pressure tank or atmosphere, the water turns cloudy and a reddish brown substance begins to form. This sediment is the oxidized or ferric form of iron that will not dissolve in water.

Iron is not hazardous to health, but it is considered a secondary or aesthetic contaminant. Essential for good health, iron helps transport oxygen in the blood. Concentrations of iron as low as 0.3 mg/l will leave reddish brown stains on fixtures, tableware and laundry that are very hard to remove. When these deposits break loose from water piping, rusty water will flow through the faucet.

Since iron combines with different naturally occurring organic materials, it may also exist as an organic complex. The combination of naturally occurring organic material and iron can be found in shallow wells and surface water. This type of iron is usually yellow or brown but may be colourless [Illinois Department of Public Health, 1999].

### 2.1.16 Manganese

Manganese ($Mn^{2+}$) is present in many soils and sediments as well as in rocks whose structures have been changed by heat and pressure. It is used in the manufacture of steel to improve corrosion resistance and hardness. Manganese is considered essential to plant and animal life and can be derived from such foods as corn, spinach and whole wheat products. It is known to be important in building strong bones and may be beneficial to the cardiovascular system. Manganese may be found in deep well waters at concentrations as high as 2 - 3 mg/l. It is hard to treat because of the complexes it can form which are dependent on the oxidation state, pH, bicarbonate-carbonate-OH ratios and the presence of other minerals, particularly iron. Concentrations higher than 0.05 mg/l cause manganese deposits and staining of clothing and plumbing fixtures. The stains are dark brown to black in nature. The use of chlorine bleach in the laundry will cause the stains to set. The chemistry of manganese in water is similar to that of iron. A high level of manganese in the water produces an unpleasant odour and taste. Organic materials can tie up manganese in the same manner as they do iron; therefore destruction of the organic matter is a necessary part of manganese removal [USEPA, 1994].

### 2.1.17 Copper

Because copper exhibits some harmful health effects and because drinking water may be a significant route of exposure to copper, it is important to know how much copper is in drinking water. A metallic taste is usually found in drinking water before copper levels are high enough to cause adverse health effects. Blue or blue green stains around sinks and plumbing fixtures are also noticed.

On the average, drinking water accounts for less than 5% of our daily copper intake. The U.S. Environmental Protection Agency (USEPA) has determined that copper levels in drinking water should not exceed 1300 ug/l. No adverse health effects would be expected if this level is not exceeded. Measures should be taken to reduce exposure to copper if this level is exceeded.

Copper rarely occurs naturally in water. Most copper contamination in drinking water happens in the water delivery system, as a result of corrosion of the copper pipes or fittings. Copper piping and fittings are widely used in household plumbing.

Because the physical and chemical characteristics of water vary, the corrosive properties of water vary as well. Factors causing corrosion include acidity (low pH), high temperature, low total dissolved solids (TDS) content and high amounts of dissolved oxygen or carbon dioxide. Generally, naturally soft water is more corrosive than hard water because it is more acidic and has low TDS. Observations have shown increased copper levels in water softened with ion exchange water softeners. If the water is not corrosive, hard water minerals are slowly deposited on the interior of plumbing. These hard water deposits form a calcium carbonate lining inside pipes and fittings which protects against copper contamination, however, it may take up to five years for an effective calcium carbonate lining to form and softening hard water with an ion exchange unit can either prevent or dissolve the calcium carbonate scale, reducing or eliminating its protective effect.

The easiest and most effective method for reducing exposure to copper is to avoid drinking or cooking with water that has been in contact with house plumbing for more than six hours.

If an elevated level of copper in drinking water is observed, it may be likely that lead levels are also elevated. This is especially true if the plumbing system contains lead solder joints, lead service lines, or brass fixtures. Since lead and copper enter drinking water under similar conditions, it is advisable to test for lead when testing for copper [WHO, 1996].

### 2.1.18 Zinc

Zinc occurs in small amounts in almost all igneous rocks. The principal zinc ores are sulphides, such as sphalerite and wurzite.The natural zinc content of soils is estimated to be 1–300 mg/kg.

- Organoleptic properties

Zinc imparts an undesirable astringent taste to water. Tests indicate that 5% of a population could distinguish between zinc-free water and water containing zinc at a level of 4 mg/liter as zinc sulphate [WHO, 1996].

- Water

In natural surface waters, the concentration of zinc is usually below 10μg/litre, and in groundwater, 10–40 μg/liter. In tap water, the zinc concentration can be much higher as a result of the leaching of zinc from piping and fittings. The most corrosive waters are those of low pH, high carbon dioxide content and low mineral salts content. In a Finnish survey of 67% of public water supplies, the median zinc content in water samples taken upstream and downstream of the waterworks was below 20 μg/liter; much higher concentrations were found in tap water, the highest being 1.1 mg/liter. Even higher zinc concentrations (up to 24 mg/liter) were reported in a Finnish survey of water from almost 6000 wells [Lahermo, 1990].

### 2.1.19 Cadmium

Cadmium is a natural, usually minor constituent of surface and groundwater. It may exist in water as the hydrated ion, as inorganic complexes such as carbonates, hydroxides, chlorides or sulphates, or as organic complexes with humic acids.

Cadmium may enter aquatic systems through weathering and erosion of soils and bedrock, atmospheric deposition direct discharge from industrial operations, leakage from landfills and contaminated sites and the dispersive use of sludge and fertilisers in agriculture. Much of the cadmium entering fresh waters from industrial sources may be rapidly adsorbed by particulate matter and thus sediment may be a significant sink for cadmium emitted to the aquatic environment [WHO, 1992].

Some data shows that recent sediments in lakes and streams range from 0.2 to 0.9 ppm in contrast to the levels of generally less than 0.1ppm cited above for fresh waters. Partitioning of cadmium between the adsorbed-in-sediment state and dissolved-in-water state is therefore an important factor in whether cadmium emitted to waters is or is not available to enter the food chain and affect human health.

Rivers containing excess cadmium can contaminate surrounding land, either through irrigation for agricultural purposes, dumping of dredged sediments or flooding. It has also been demonstrated that rivers can transport cadmium for considerable distances up to 50 km from the source [WHO, 1992].

### 2.1.20 Lead

Source - Lead ($Pb^{2+}$) found in fresh water usually indicates contamination from metallurgical wastes or from lead-containing industrial poisons. Lead in drinking water is primarily from the corrosion of the lead solder used to put together the copper piping. Lead in the body can cause serious damage to the brain, kidneys, nervous system and red blood cells.

Except in isolated cases lead is probably not a major problem in drinking water, although the potential exists in cases where old lead pipe is still in use.

Treatment - Lead can be reduced considerably with a water softener. Activated carbon filtration can also reduce lead to a certain extent. Reverse Osmosis can remove 94 to 98 % of the lead in drinking water at the point-of-use [Manahan, 1994].

### 2.1.21 Sodium

Sodium levels in drinking water that are less than 20 mg/L are considered safe for most people. In the seacoast area however, elevated levels of sodium and chloride occur naturally due to the proximity to seawater. Substantially higher levels of sodium and chloride may also be due to contamination by activities of man including: the use of road de-icing salts, discharges from water softeners, human or animal waste disposal, leachate from landfills and many other activities.

At present there are no health standards for sodium and chloride in drinking water. A review by EPA in the mid-1980s showed that elevated levels of sodium in drinking water did not cause high blood pressure or heart disease, rather only that sodium should be avoided by those people who already had such medical conditions.

It is important to note that sodium is an essential nutrient. The Food and Nutrition Board of the National Research Council recommends that most healthy adults need to consume at least 500 mg of sodium per day, and that sodium intake be limited to no more than 2400 mg/day. A Food and Drug Administration publication states that most

American adults tend to eat between 4,000 and 6,000 mg of sodium per day [USEPA, 1994].

### 2.1.22 Potassium

Source - Potassium ($K^+$) is an alkaline metal closely related to sodium. It is seldom that one sees it analyzed separately on a water analysis. Potassium is not a major component in public or industrial water supplies. Potassium is, however, essential in a well balanced diet and can be found in fruits such as bananas [USEPA, 1994].

The potassium content of drinking water varies greatly depending on its source. It tends to be larger in mineral waters than ordinary tap water. However, on average, the daily water consumption by adults supplies less than 0.1% of their potassium intake. But tap water is also used to make beverages like tea, coffee, beer and wines. The average total potassium intake in beverages can supply about 13% of the total daily intake of adults [USEPA, 1994].

### 2.1.23 The atomic absorption Spectrophotometer (AAS)

**Technique:** The sample solution is aspirated into a flame and the sample element is converted to atomic vapour. The flame then contains atoms of the elements. Some are thermally excited by the flame but most remain in the ground state. These ground state atoms can absorb radiation given off by a special source (i.e. hollow cathode lamp or electrodeless discharge lamp) made from that element.

The wavelengths of radiation given off by the source are the same as those absorbed by the atoms in the flame.

The absorption follows the Beer's law i.e. absorption is directly proportional to the path length in the flame and to the concentration of atomic vapour in the flame.

Both of these variables are difficult to determine, but the path length can be held constant and the concentration of atomic vapour is directly proportional to the concentration of the analyte in the solution being aspirated [Christian, 1994].

- **Analysis for metals**

Total metals include all the metals, inorganically and organically bound and both dissolved and particulate. Analysis for total metals involves digestion of samples without preliminary filtration. Nitric acid adequately digests many metals. Nitrate is an acceptable matrix for flame and electrothermal atomic absorption. Some samples may require the addition of perchloric or sulphuric acids for complete digestion [Christian, 1994].

### 2.1.24 Taste

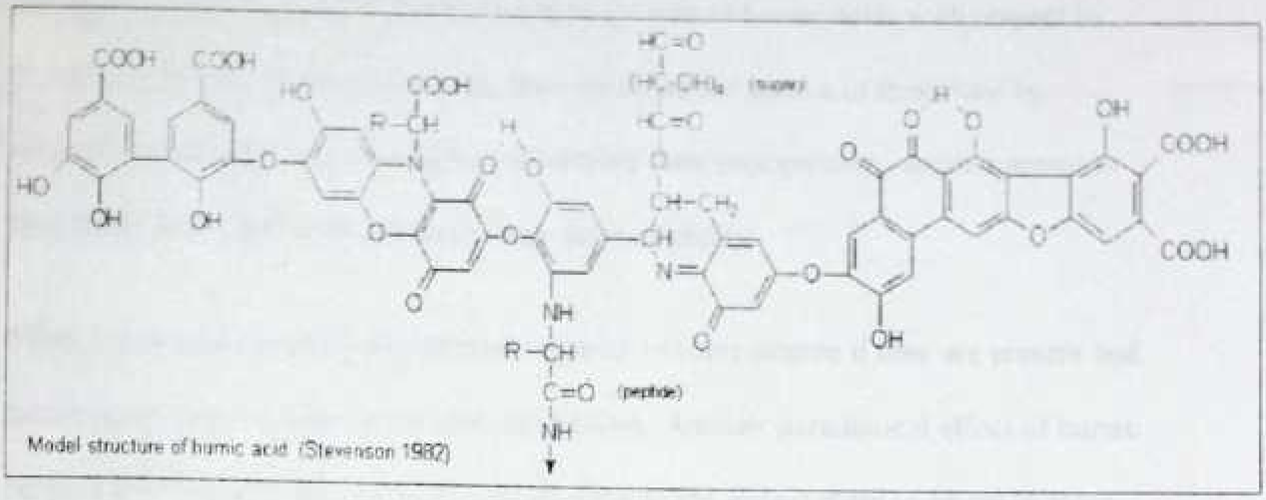
Source - Generally, individuals have a more acute sense of smell than taste. Taste problems in water come from total dissolved solids (TDS) and the presence of such metals as iron, copper, manganese or zinc. Magnesium chloride and magnesium bicarbonate are significant in terms of taste. Fluoride may also cause a distinct taste. Taste and odour problems of many different types can be encountered in drinking water. Troublesome compounds may result from biological growth or industrial activities. The tastes and odours may be produced in the water supply, in the water treatment plant from reactions with treatment chemicals, in the distribution system, and or in the plumbing of consumers. Tastes and odours can be caused by mineral contaminants in the water, such as the "salty" taste of water when chlorides are 500 mg/l or above. Decaying vegetation is probably the most common cause for taste and odour in surface water supplies. In treated water supplies chlorine can react with organics and cause taste and odour problems.

Treatment - Taste and odour can be removed by oxidation-reduction or by activated carbon adsorption. Aeration can be utilised if the contaminant is in the form of a gas, such as $H_2S$ (hydrogen sulphide). Chlorine is the most common oxidant used in water treatment, but is only partially effective on taste and odour. Potassium permanganate and oxygen are also only partially effective. Chloramines are not at all effective for the treatment of taste and odour. The most effective oxidisers for treating taste and odour are chlorine dioxide and ozone. Activated carbon has an excellent history of success in treating taste and odour problems. The life of the carbon depends on the presence of organics competing for sites and the concentration of the taste and odour causing compound [Keyser, 1997].

### 2.1.25 Organic Acids (Humic Substances)

**Humic substances**: The term refers to a series of relatively high-molecular-weight, brown to black coloured substances formed by secondary synthesis reactions. The term is used as a generic name to describe coloured material or its fractions obtained on the basis of solubility characteristics [Craig, 1996].

**Humic acids** - the fraction of humic substances that is not soluble in water under acidic conditions ($pH < 2$) but is soluble at higher pH values. They can be extracted from soil by various reagents and which is insoluble in dilute acid. Humic acids are the major extractable components of soil humic substances. They are dark brown to black in colour



Model structure of humic acid (Stevenson 1982)

Figure 2.1 Model Structure of Humic Acid

Humic acids are a complex mixture of partially "decomposed" and otherwise transformed organic materials. The chemistry of their formation is quite complex and freshwater humic acids can come from a variety of sources, most of which are on land (decomposing terrestrial vegetation). These substances wash into lakes and rivers, undergoing further transformations along the way and ultimately into the ocean. There are several subclasses of humic acids, (tannins, lignins, fulvic acids) which are partially "resolvable" based on some fairly simple physicochemical criteria, but the criteria for these separations is primarily the convenience of the methods used, and to some degree elucidating their origins, as opposed to their functional impact on aquatic ecosystems. They all tint the water yellow and bind all cations.

All share these characteristics:

A substantial fraction of the mass of the humic acids is in carboxylic acid functional groups, which endow these molecules with the ability to chelate positively charged multivalent ions ($Mg^{2+}$, $Ca^{2+}$, $Fe^{2+}$ and most other "trace elements" of value to plants, as well as other ions that have no positive biological role, such as $Cd^{2+}$ and $Pb^{2+}$).This chelation of ions is probably the most important role of humic acids with respect to living systems. By chelating the ions, they facilitate the uptake of these ions by several mechanisms, one of which is preventing their precipitation, another seems to be a direct and positive influence on their bioavailability.

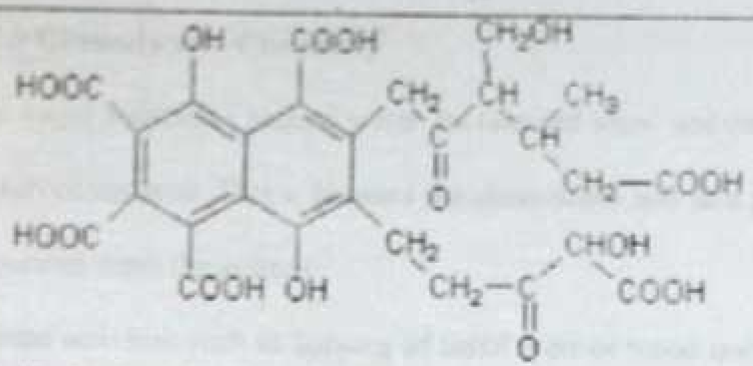
Many organisms can exploit dissolved organics to some degree if they are present and humic acids may be taken up by this mechanism. Another paradoxical effect of humic acids is the detoxification of heavy metals. One might expect them to be made more, not less toxic by humic acids, but studies seem to indicate a detoxifying effect.

Humic acids also have a smaller fraction of phenolic functional groups, which can be detected various chemical methods. They are derived from peptide, lipid and carbohydrate precursors. Their formation and diagensis is partially mediated by aquatic bacteria and enzymes.

They are all complex chemically, polydisperse (having different composition and molecular weights) and eventually hit a diagenic state where it is difficult to change them further [Craig, 1996].

Terrestrial humic acids tend to be more "aromatic" in nature (having more benzene- and phenol-like components) while marine humic acids tend to be more aliphatic in nature. The distributions seem to be overlapping, so there is a difference in degree. There are certainly aliphatic-like (grease, oil, fat) components in terrestrial humic acids, as there are aromatic components in marine humic acids.

**Fulvic acids** - the fraction of humic substances that is soluble in water under all pH conditions. They remain in solution after removal of humic acid by acidification. Fulvic acids are light yellow to yellow-brown in colour.



Model structure of fulvic acid by Buffle

**Figure 2.2 Model Structure of Fulvic Acid**

**Humins**: The fraction of humic substances that is not soluble in water at any pH value and in alkali. Humins are black in color.

### 2.1.26 Aesthetic Property of Humic Acids

1. Colour in drinking water may be due to the presence of coloured organic substances; the presence of metals such as iron, manganese and copper or the presence of highly coloured industrial wastes, the most common of which are pulp and paper and textile wastes.

Although the presence of colour in drinking water may be indirectly linked to health, its primary importance in drinking water is aesthetic. Experience has shown that consumers whose drinking water contains aesthetically displeasing levels of colour may seek alternative possibly unsafe sources.

2. Levels of colour above 15HU can be detected in a glass of water by most people.

3. The aesthetic objective for colour has therefore been set at 15HU. The provisions of treated water at or below this limit will ensure rapid notification by consumers should problems leading to the formation of colour arise in the distribution system. In addition, interferences by colour in water treatment processes and analytical procedures will be diminished [Black *et al.*, 1963].

### 2.2.0 Groundwater Chemistry

The major sources of ground water are rain and snow and they contain very little dissolved material. This is because the atmosphere acts as a giant still that removes impurities from the system.

Human activities such as burning of fossil fuels or wood and geological events such as volcanic gases emit compounds into the atmosphere that later are dissolved in falling rain.

Generally rainwater contains less that 10 to 20 mg of dissolved substances per litre of solution.

By the time precipitation has percolated through soil, sediments and rocks to replenish the ground water it has accumulated many hundreds of times those amounts of dissolved substances.

The minerals in rocks are soluble in water and each mineral has a different solubility in pure water. The solubility varies with the acidity of the water and the amount of oxygen dissolved in it.

Ground water readily dissolves the most soluble minerals in rocks. With increasing depth, the amount and types of materials dissolved in ground water vary with deeper waters generally having higher concentrations of salts and less oxygen.

As soon as rain water infiltrates the soil and become ground water, its composition begins to change.

Microbes use oxygen to decompose plant and animal matter .With increasing depth, ground water is depleted of oxygen.

Nitrogen generated from soil forming processes dissolves in water to form nitrogen compounds ($NO_2$ and $NO_3$). Nitrogen is essential for plant growth and its present in large quantities in manure and artificial fertilizers which farmers often use in their production. The level of nitrate in groundwater has increased rapidly in farming areas in the recent decades.

As water moves through soil rich in organic matter much $CO_2$ gas is dissolved and the reaction of the $CO_2$ and $H_2O$ forms carbonic acid $H_2CO_3$, a weak acid of pH 5.7, which in turn dissolves rocks in the form of $CaCO_3$.

Magnesium and potassium are also common in groundwater from the dissolution of rocks sulphide ions released in the weathering. Sulphide minerals are also present in minute quantity.

Calcium and Magnesium ions together contribute to water hardness. Hard water contains 50 to 100mg or more of dissolved calcium and magnesium ion per litre of water. These ions can crystallize to form mineral deposits that leave rings in bathtubs and scaly deposits in water pipes.

There is continuous dissolution of solids as water moves deep into the subsurface.

The total amount of dissolved solids rises but there is much exchange of ions between water and mineral surfaces.

Clay minerals found in rocks and sediments are generally associated with large amounts of sodium during deposition in offshore marine environments.

Cation exchange occurs between calcium and magnesium from the water and sodium on the exposed surfaces of clay minerals result in water rich in sodium bicarbonate.

Clay particles have a large surface area because of their small size. This makes clay exposed to a lot of exchangeable sodium ions.

The age of ground water increases with depth. Studies of carbon in groundwater using radiometric dating have shown that, its age can be as long as 10,000 to 40,000 years in the deeper part of some aquifers.

The trend of groundwater evolution with depth and age is a transformation from bicarbonate-rich water to sulphate ($SO_4^{2-}$) rich water, then finally to brine, a water solution rich in sodium chloride.

The circulation of water at great depths is usually much more restricted than at shallow levels. Sodium chloride which is very soluble in water is not flashed out from ground water.

Many hydrologists in the earliest times thought the brine pumped from deep wells were ancient marine water trapped in sediments as they were laid down.

It is now clear that groundwater can evolve to become more saline with depth and age [Merritis *et al.*, 1998].

### 2.3.0 Groundwater contamination factors

There are a number of important factors that determine whether a chemical is likely to reach and become a groundwater contaminant. The major factors are:

- Properties of the chemical
- Properties of the soil
- Existing conditions at the site
- Human actions or practices

### 2.3.1 Properties of the chemical

Each chemical that comes into contact with soil moisture has the characteristics of solubility, adsorption, volatility and degradation.

Solubility is a measure of how readily a chemical dissolves in water. Water moving down through soil carries water-soluble chemicals with it. This leaching occurs continuously as water moves from the surface down to the groundwater aquifers.

Adsorption is the ability of a chemical to be held on the surface of soil particles or soil organic matter. A chemical that is held tightly by soil is less likely to be carried downward by leaching.

Volatility determines the ability of a chemical to be lost to the atmosphere. A highly volatile chemical may escape to the atmosphere before it becomes dissolved in water. This may not be true of chemicals that are also highly water-soluble.

Degradation is the chemical breakdown of a substance in soil or water. The degradation of a chemical may be due to sunlight, soil microorganisms and other chemical and physical properties. A chemical that degrades slowly is more likely to be moved downward by leaching.

A type of contaminant that is especially troublesome is the group of chemicals known as dense non-aqueous phase liquids or DNAPLs. These include chemicals used in dry cleaning, wood preservation, asphalt operations, machining and in the production and repair of automobiles, aviation equipment, munitions and electrical equipment. These substances are heavier than water and they sink quickly into the ground. This makes spills of DNAPLs more difficult to handle than spills of petroleum products. Except in large cities, drinking water is rarely tested for these contaminants [Vandre, 1995].

### 2.3.2 Properties of the soil

The important characteristics of the soil which help determine groundwater contamination are texture, permeability and organic matter content.

Soil texture is the relative proportions of sand, silt and clay. Coarse, sandy soils allow more water movement by percolation and have less capability to adsorb chemicals than clay. The coarser the texture of a soil the greater the chance of a chemical reaching groundwater.

Soil permeability is a measure of how fast water moves downward through a soil. Highly permeable soils have a greater capability to lose chemicals to leaching. Applying pesticides or fertilizers to highly permeable soils should be done in such a way that leaching is kept to a minimum.

Soil organic matter influences soil capability to hold water and to adsorb chemicals. The incorporation of organic matter into a soil will increase the capability and decrease the downward movement of chemicals by leaching [Vandre, 1995].

### 2.3.3 Existing conditions at the site

The depth to groundwater at a specific location is important because the soil between the surface and groundwater acts as a filter. Less soil means more leaching, less adsorption and less degradation. When groundwater is close to the surface, care must be taken whenever pesticides or fertilizers are applied or incorporated. Smaller applications, split applications or no application may be the best alternative.

The geologic conditions of a site should be determined to assess groundwater vulnerability. Layers of gravel above the groundwater area do not offer much protection against percolation or leaching. A layer of clay does create an effective filter for many chemicals. A steep slope increases the potential for surface runoff and the subsequent movement of chemicals to other vulnerable areas.

Climate is another consideration at every location. Excessive rainfall increases percolation and leaching. Cold soils slow the rate of degradation and increase the time the chemical is available for leaching [Vandre, 1995].

### 2.3.4 Human actions or practices

The application of a pesticide, fertilizer or any other chemical is regulated by the landowner or applicator. Application methods and dosage can influence the leaching of the chemical. Soil incorporation or injection of a pesticide poses a greater groundwater hazard than foliage or surface application. Decreasing the amount of pesticide applied through the use of effective alternatives will also protect groundwater resources. This can be accomplished by using pesticides which are less susceptible to leaching and surface runoff.

The timing of pesticide application can be important in minimising groundwater risk. Application prior to a heavy rain or irrigation may result in leaching rather than effective use [Vandre, 1995].

### 2.4.0 Sources of Ground water contamination

Ground water is contaminated by the following:

### 2.4.1 Agricultural sources of Ground water contamination

Pesticides, fertilizers, herbicides and animal waste are agricultural sources of ground water contamination. The means of agricultural contamination are varied and numerous, but some examples are:

Spillage of fertilizers and pesticides during handling runoff from the loading and washing of pesticide sprayers or other application equipment using chemicals uphill from or within a few hundred feet of a well.

Agricultural land that lacks sufficient drainage is considered by many farmers to be lost income land. So they may install drain tiles or drainage wells to make the land more productive. The drainage well then serves as a direct conduit to ground water for agricultural wastes which are washed down with the runoff, storage of agricultural chemicals near conduits to ground water, such as open and abandoned wells, sink holes or surface depressions where water is likely to accumulate. Contamination may also occur when chemicals are stored in uncovered areas, unprotected from wind and rain or are stored in locations where the ground water flows from the direction of the chemical storage to the well.

Mixing and distributing pesticides and fertilizers with irrigation water can cause ground water contamination if more chemicals are applied than crops can use.

Fields with over-applied or misapplied fertilizers, herbicides, insecticides and fungicides could introduce these contaminants into the ground water:

Organic compounds, excess cadmium, Chloride, Mercury and Selenium.

Feedlots are potential contamination sources. Animal waste is often collected in impoundments from which the wastes may infiltrate the ground water. Runoff could also enter an aquifer through a poorly sealed well casing. Livestock waste is a source of Nitrate, Coliform Bacteria, total dissolved Solids and sulphates .

Within the garage or farm equipment shed, chemicals that are improperly stored or disposed off that could potentially contaminate ground water include Paint containing lead and barium, Gasoline and oils containing volatile organic compounds.

Many sources of ground water contamination can originate in the house or other farm residences such as trailers or dormitories. Leaks, spills, overloading or poor maintenance of septic systems can result in the following contaminants entering ground water: Coliform Bacteria ,Nitrate, Total Chloride, Sodium, Sulphates, detergents and Chromium .

Both aboveground and underground storage tanks (USTs) are at risk of leaking and releasing gasoline which contains benzene.

Abandoned wells that have not been plugged or dismantled provide a potential pathway (direct route) for water to flow directly from the surface to the aquifer, carrying whatever contaminants which are on the surface into the ground water. Open wells can become contaminated by the working fluids, such as grease and oils from the pump or from contaminants from the surface if the well cap is not tight or if the casing lining the well is cracked or corroded. In addition, many older farm wells were merely shallow holes dug into the ground. These wells can easily be contaminated and are also a safety hazard to children and animals [USEPA, 1997].

### 2.4.2 Industrial sources of Ground water contamination

Modem economic activity requires transportation and storage of material used in manufacturing, processing and construction. Along the way, some of this material can be lost through spillage, leakage or improper handling. Even the cleanup of spills may pose a threat to ground water when the spills are flushed with water rather than cleaned up with absorbent substances.

The disposal of wastes associated with the above activities contributes another source of ground water contamination. Some businesses, usually without access to sewer systems, rely on shallow underground disposal. They use cesspools or dry holes, or send the wastewater into septic tanks. Any of these forms of disposal can lead to contamination of underground sources of drinking water. Dry holes and cesspools introduce wastes directly into the ground. Septic systems cannot treat industrial wastes. Wastewater disposal practices of certain types of businesses, such as automobile service stations, dry cleaners, electrical component or machine manufacturers, photo processors and metal platters or fabricators are of particular concern because the waste they generate is likely to contain toxic chemicals.

Other industrial sources of contamination include cleaning off holding tanks or spraying equipment on the open ground, disposing of waste in septic systems or dry wells, and storing hazardous materials in uncovered areas or in areas that do not have pads with drains or catchments basins.

Although businesses may run a "clean shop", small amounts of waste fluids can end up on the shop floor and be washed down floor drains. These drains may be connected to shallow injection well systems, which are not designed to handle the industrial chemicals typically used by businesses such as those listed above. Even low concentrations of certain contaminants can accumulate through time.

Underground and above ground storage tanks holding petroleum products, acids, solvents and chemicals can develop leaks from corrosion, defects, improper installation or mechanical failure of the pipes and fittings.

Mining of fuel and non-fuel minerals can create many opportunities for ground water contamination. The problems stem from the mining process itself, disposal of wastes, and processing of the ores and the wastes it creates [USEPA, 1997].

### 2.4.3 Residential sources of Ground water contamination

A major cause of ground water contamination is effluent (outflow) from septic tanks and cesspools. Misuse of these systems for disposal of anything other than domestic or sanitary waste can pose a substantial threat to ground water.

Residential wastewater systems can be a source of many categories of contaminants, including bacteria, viruses, nitrates from human waste and organic compounds. Injection wells used for domestic wastewater disposal (septic systems, cesspools, drainage wells for storm water runoff, ground water recharge wells), are of particular concern to ground water quality if located close to and up gradient of drinking water wells.

Improper storing or disposing of household chemicals such as paints, synthetic detergents, solvents, oils, medicines, disinfectants, pool chemicals, pesticides, batteries, gasoline and diesel fuel can lead to ground water contamination. When stored in garages or basements with floor drains, spills and flooding may introduce such contaminants into the ground water. When thrown in the household trash, the products will eventually be carried into the ground water because community landfills are not equipped to handle hazardous materials. Similarly, wastes dumped or buried in the ground can contaminate the soil and leach into the ground water.

As urban areas grow, there is an increase in rain water runoff caused by the addition of paved surfaces. Some municipalities use storm water drainage wells to dispose of this additional runoff, particularly if the area is not served by storm sewers nor has a limited sewer system. These low-cost, low-tech wells can serve as a conduit to ground water for runoff from streets, roofs, construction sites and landscaped areas. Storm water drainage wells that communities use to control water during storm events pose a threat to ground water particularly in karsts areas or areas with a high water table.

Fertilizers, herbicides, insecticides, fungicides and pesticides applied to the lawn and garden contain hazardous chemicals that can travel through the soil and contaminate ground water.

In the garage, items that are improperly used, stored or disposed of may potentially contaminate ground water, especially if there is a drain to the ground in the floor of the garage. Sources include, batteries that contain lead, cadmium or mercury. Paint containing lead and barium. Gasoline and oil containing compounds, barium from diesel fuel combustion .

Water used in the home and entering a septic system or sewer system may contain detergents from dishwashing and laundry, organic compounds from the garbage, disposal Bacteria, nitrates, sulphates from sewage, greases and oils. Cleaning agents, aerosol sprays, coolants and solvents which all contain carbon tetrachloride household pesticides .

Water percolating through landfills is known as leachate. Leachate from landfills that contain household and other waste may pick up dissolved solids and Volatile organic compounds.

Lawns with over applied or misapplied fertilizers, herbicides, insecticides and fungicides might introduce these contaminants tetrachloride and heavy metals such as manganese into groundwater [USEPA, 1997]

### 2.4.4 Natural sources of Ground water contamination

Ground water contains some impurities, even if it is unaffected by human activities. The types and concentrations of natural impurities depend on the nature of the geological material through which the groundwater moves and the quality of the recharge water.

Ground water moving through sedimentary rocks and soils may pick up a wide range of compounds such as magnesium, calcium and chlorides. Some aquifers have high natural concentration of dissolved constituents such as arsenic, boron and selenium.

The effect of these natural sources of contamination on ground water quality depends on the type of contaminant and its concentration.

Some of the contaminants that occur naturally are:

Aluminium, Arsenic, Barium, Chloride, Chromium, Coliform Bacteria, Copper, Fluoride, Hardness, Iron, Lead, Manganese, Mercury, Nitrate, Selenium, Silver, Sodium, Sulfate, Zinc [USEPA, 1997].

### 2.5.0 Speciation of metals

Legislation governing the maximum permissible levels of a polluting element in an environmental sample such as surface or groundwater refers to total concentrations rather than the chemical form of the element.

This total concentration however provides no information concerning the fate of the elements in terms of its interaction with sediments, its ability to cross biological membranes (bioactivity) or its resultant toxicity.

Changes may dramatically affect the toxicity of a metal. For example, inorganic mercury species are generally unable to cross biological membranes and thus have low toxicity.

Alkyl mercury species are lipids soluble and hence extremely toxic to aquatic organisms. It is therefore imperative to have information concerning the chemical form of an element (speciation) in order to assess its environmental impact [Fifield *et al.*, 1997].

### 2.6.0 Origin of Groundwater Development

The use of groundwater has been with man way back in the ancient times.

Most of the ancient civilisations obtained their water supplies from the groundwater as well as surface waters.

It is reported that in the 1183BC crusade prisoners in Egypt constructed a Well excavated out of bedrock which they called the Joseph's Well to ensure the citadels supply of water [Osiakwan, 2002]

The Holy Bible makes references to groundwater, first in the story of Moses striking a rock with his rod and bringing forth a fountain of water [The Bible Society, 1971]. Another instance in the Bible is when an angel of the Lord appeared to Hagar in the wilderness and directed her to a Well [The Bible Society, 1971].

The drilling instead of the usual digging of Wells began in the 12th century, with the successful drilling of a well at Artois, France in 1226.

The term Artesian usually used for drilled Wells comes from the name of this village. An artesian Well completed in 1841 at Grenelle near Paris was for many years the deepest Well in the world.

Another well known Well is the one at St. Augustine Florida in the United States of America [Osiakwan, 2002].

### 2.7.0 History of Borehole construction in Ghana

The genesis of groundwater development in Ghana can be traced from the 19th century where communities dwelled on hand dug wells for their water supply.

The colonial governments in 1920-1945 initiated a national hand-dug well program under the patronage of the Rural Water Division a wing of the then Gold Coast Survey Department [Osiakwan, 2002].

The construction of Boreholes in Ghana began in the 1940s. This was to increase the water supply to rural and urban communities. Since then it is believed that thousands of hand-Dug wells and boreholes have been constructed both by local and external donors.

The Ghana water Company by the year 2000 had constructed 2500 boreholes all over the country.

The world Vision international between 1985 to June 2000 had drilled 1523 boreholes throughout the country [World Vision, 2000].

Through the help of the German government, another 3000 boreholes have been drilled in southern Ghana between 1978 and 1983 [Issah, 2000].

The government of Ghana through collaboration with bodies like Community water and sanitation Agency, World Vision International, Catholic Relief Agency and many other non-governmental organisations currently have been drilling thousands of boreholes annually in the country.

This has made borehole water an indispensable ally in most Ghanaian communities.

### 2.8.0 The quality of ground water in Ghana

Ground water needs to be assessed globally since it does not respect national boundaries. It has to be started on local, national, regional and finally international levels.

Generally, groundwater in Ghana can be said to be of good quality for all purpose use. The average pH lies in the range of 3.5-6.0 with high levels of fluoride, manganese and Iron in certain localities. There is also high mineralization resulting in TDS in the range of 1458-2000mg/L in some coastal aquifers especially in the greater Accra Region.

Groundwater with low pH is normally found in the forest regions of the southern belt of the country.

About 30% of boreholes in Ghana have a problem with its Iron content. 1-64 mg/L of Iron is present in almost all geological formations.

The high iron content originates from the corrosion of borehole pumps with water and partly from the aquifers. The exact contribution from the aquifers is however not known [MOWH, 1998].

Water in shallow hand dug wells is normally turbid and polluted as they contain high levels of nitrate in the range of 30-60mg/L and abundant Coliform [MOWH, 1998].

According to a work by Issah on the quality of ground water in some borehole wells sampled from the Upper East and the Northern regions of Ghana, he discovered high levels of $NO_3^-$, $PO_4^{3-}$, Mn , Pb, Fe and $F^-$ in some of the wells sampled. These values were compared to W.H.O and G.W.S.C. guidelines [Issah, 2000].

In the Ashanti Region, the World Vision and the Community Water and Sanitation Agency (CWSA) have been involved in the construction of boreholes and analysis of its water.

The CWSA's work in, Sekyere East, Ahafo-Ano South, Ahafo-Ano North, and Bosomtwi-Atwima-Kwanwoma districts in the Ashanti region revealed that the levels of $NO_2^-$, Mn and Fe were high among most of the districts while $NO_3^-$ level was high in parts of the Sekyere-East District. The levels of the determined parameters for the Amansie West district were all below the WHO guidelines [CWSD, 1999].

# CHAPTER THREE

## 3.0 METHODOLOGY

### 3.1.0 STUDY AREA

The research was conducted in the Bosomtwi-Atwima-Kwanwoma and the Ejisu-Juaben Districts of the Ashanti Region of Ghana. The Ashanti region is situated in the southern belt of Ghana [Figure 3.1].

Ejisu-Juaben (E-J) and Bosomtwi-Atwima-Kwanwoma (BAK) are among the 21 administrative districts in the Ashanti Region of Ghana. The two districts are in close proximity.

E-J stretches over an area of 637.2Km$^{2}$ while BAK has an area of 681.799Km$^{2}$.

E-J has a population of 124,176 and BAK has 145,524 inhabitants according to the 2000 Population and Housing Census [Osiakwan, 2002]

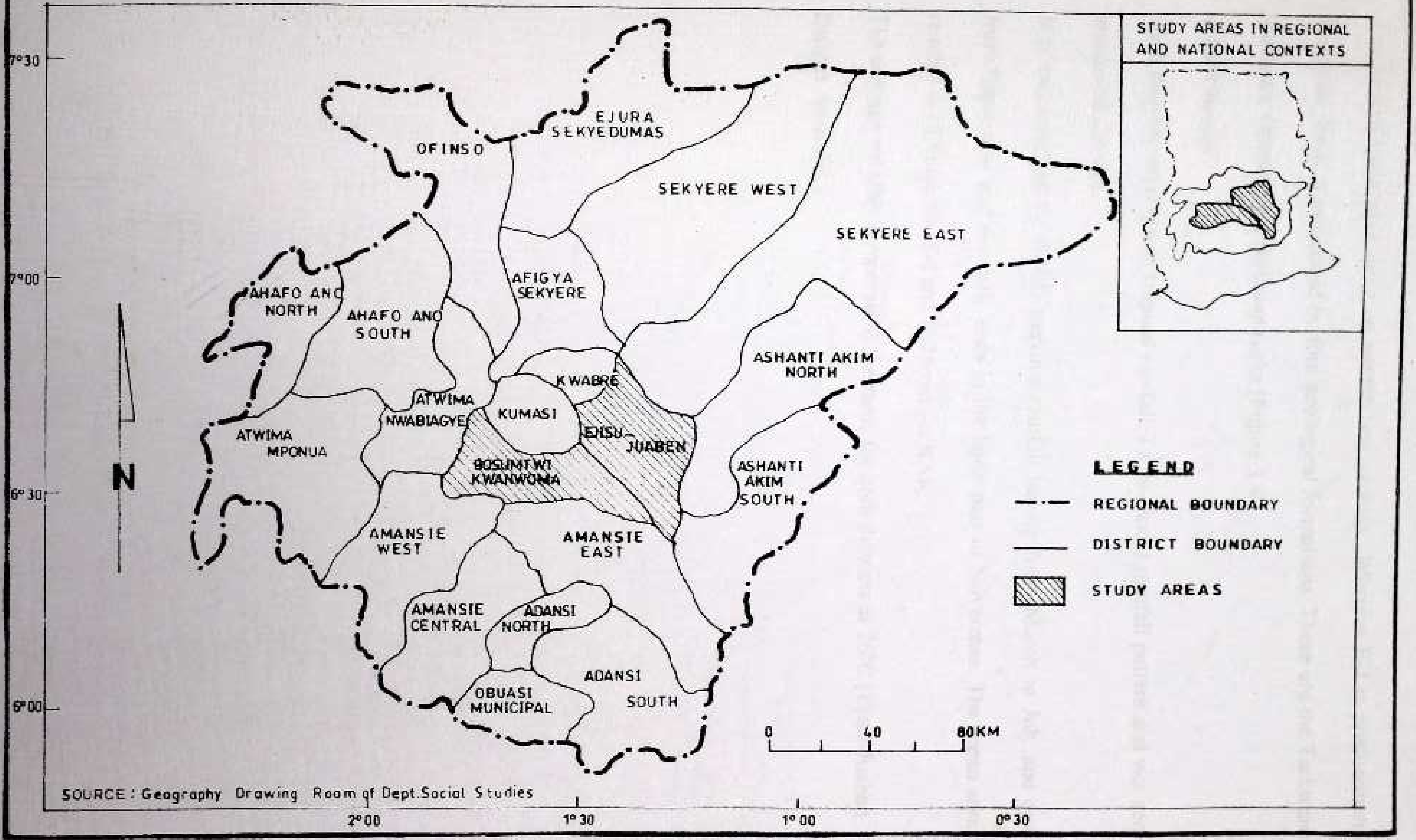
### 3.1.1 Location

The E-J district is located in the central part of the Ashanti region. It lies within latitudes 1°15$^{0}$N and 1°45$^{0}$N and Longitudes 6°15$^{1}$W and 7°00$^{1}$W. It shares boundaries with six (6) other Districts of the region [Figure 3.2].

To the North East and North West of the District are Sekyere East and Kwabere Districts, to the south are Bosomtwi-Atwima-Kwanwoma and Asante-Akim South Districts, to the East is the Ashanti - Akim North District and to the West is the Kumasi Metropolis.

The BAK on the other hand lies within latitudes 6°28$^{1}$ N to 6°4$^{1}$N and longitudes 1°20$^{1}$W to 1°50' W [Figure 3.3].

The district shares boundaries with five other districts namely; Ejisu-Juaben, Atwima and Kumasi Metropolitan Assembly to the north, Asante-Akyem district to the East and Amansie-East district to the south.



SOURCE : Geography Drawing Room of Dept.Social Studies

FIGURE. 3.1 Ashanti Region of Ghana showing Administrative Districts

### 3.1.2 Geology

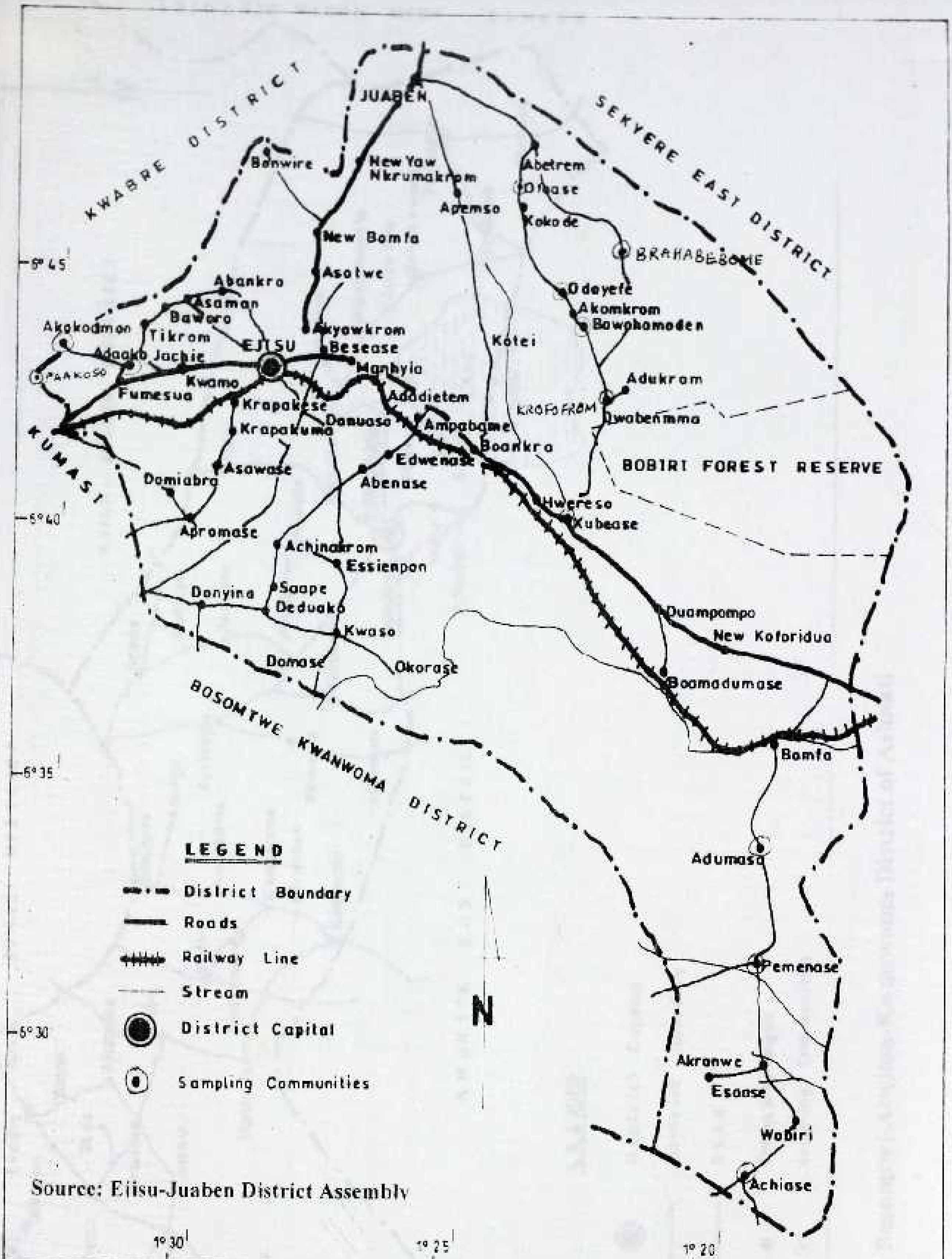
The two districts have quite an intersecting geology. Whereas E-J is predominantly Birimian, BAK is embedded by four geological formations. These are the Tarkwaian, Voltaian, Granitic and Birimian rocks [Figure 3.4].

### 3.1.3 Climate

Both districts experiences tropical rainfall, i.e. bi-modal rainfall pattern and wet semi-equatorial climate.

It is characterised by double maxima rainfall lasting from March to July and again from September and normally ends in the latter part of November. The mean annual rainfall is 1200mm for E-J and 1625mm for BAK.

The average monthly temperate is the same for both districts at 26°C [Ejisu-Juaben District Assembly].



Source: Ejisu-Juaben District Assembly

FIGURE 3.2: Ejisu-Juaben District of Ashanti

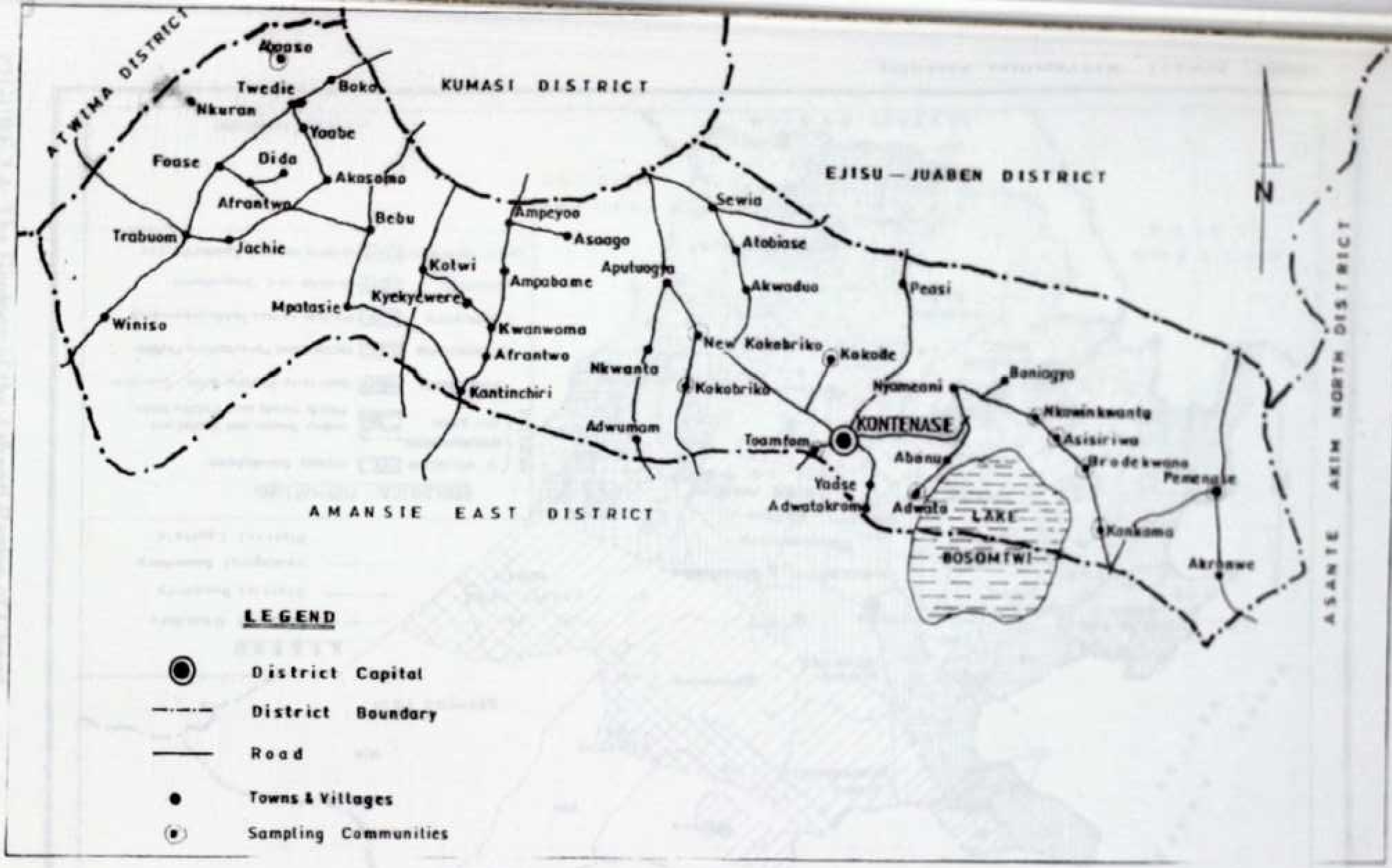
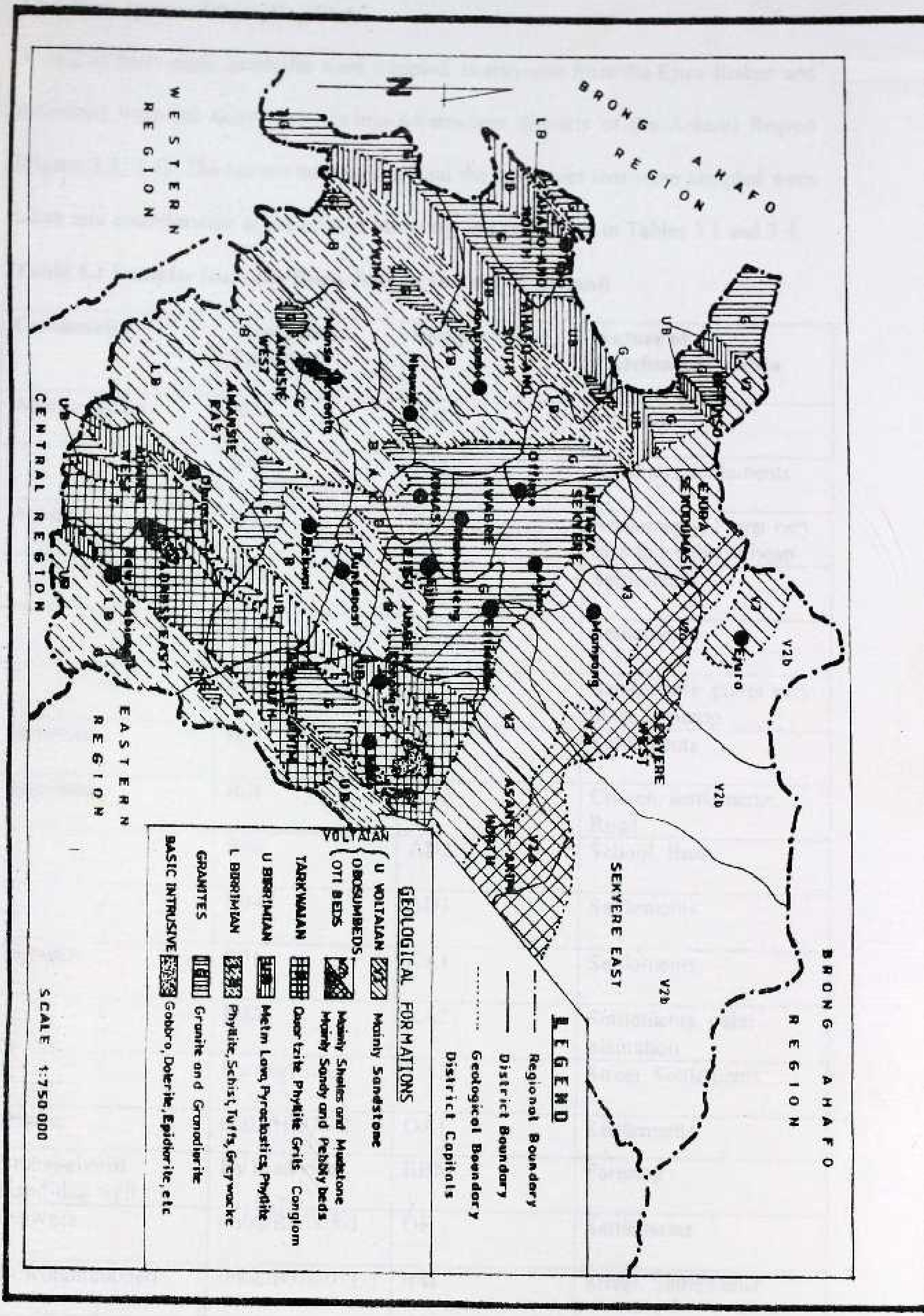


FIGURE 3.3: Bosomtwi-Atwima-Kwanwoma District of Ashanti



SOURCE: Kumasi Metropolitan Assembly

FIGURE 3.4: The Geology of the Ashanti Region of Ghana

### 3.2.0 Description of Sampling Sites

A total of thirty-eight boreholes were sampled, twenty-one from the Ejisu-Juaben and seventeen from the Bosomtwi-Atwima-Kwanwoma districts of the Ashanti Region [Figure 3.2, 3.3]. The human activities around the boreholes that were sampled were taken into consideration at the time of sampling and are shown in Tables 3.1 and 3.4.

**Table 3.1 Samples from the Ejisu-Juaben District of Ashanti**

| Community | Borehole # / Location | Sample Name | Nature of Catchments within 50m |
|---|---|---|---|
| Adarko Jachie | B01 | AJ1 | Farming |
| √ | B02 | AJ2 | Road and settlements |
| Achiase | B01 | AC3 | Settlements, Pump very lose to a rubbish heap |
| √ | B02 | AC4 | Settlements |
| √ | B03 | AC2 | Settlement |
| √ | B04 | AC1 | Settlements ,gutter very close to pump |
| Peminase | B01 | PA1 | Settlements |
| Adumasa | B01 | AD3 | Church, settlements, Road |
| √ | B03 | AD2 | School, Bush |
| √ | B04 | AD1 | Settlements |
| Kubease | B01 | KA1 | Settlements |
| √ | B02 | KA2 | Settlements, palm plantation |
| √ | By road side | KA3 | Street, Settlements |
| Ofoase | 0602/H/075-2 | OA1 | Settlements |
| Brahabebome Hand-dug well | By road side | BBM | Farming |
| Odoyefe | 0602/B3/005-1 | OF | Settlements |
| Bowohommoden | 0602/B3/8-071-1 | BM | Street, Settlements |

|  |  |  |  |
|---|---|---|---|
| Krofofrom | By road side | KF | Settlements |
| Ejisu | Ejisu Sec.Sch. | EJ1 | School |
| Paakoso | By road side | PS | Street. Settlements |
| Akokoamon | 0602-A4-/c/036-2 | AM | Farming ,Washing |

**Table 3.2 Samples from the Bosomtwi-Atwima -Kwanwoma District of Ashanti**

| Community | Borehole # / Location | Sample Name | Nature of Catchments within 50m |
|---|---|---|---|
| Adwafo | 0602B3/C/073-3 | A1 | Washing, Farming ,Building construction |
| Toamfom | 0602B3/G/083-1 | TA1 | Settlements |
| √ | 0602B3/G/083-2 | TA2 | Washing ,Settlements, |
| Kokodee | 0602B3/G/023-7 | OD1 | Settlements |
| √ | 0602B3/G1/023-6 | OD2 | Farming |
| New Kokobriko | 0602A4/I/003-3 | NKK1 | Plantain farming, Settlements |
| Kokobriko (Old) | 0602A4/I/035-1 | OKK1 | Onion farming. settlements |
| √ | 0602A4/I/035-2 | OKK2 | settlements |
| Atobease | 0602A4/F/077-2 | AT1 | settlements |
| √ | 0602A4/F/077-1 | AT2 | settlements |
| Aboaso | Close to School park | AB1 | School field, Settlements |
| √ | Behind school building | AB2 | School. Settlements |
| Konkoma | At School | KKM | School |
| Brodekwano | 0602B3/H/038-1 | BKA1 | settlements |
| √ | 0602B3/H/038-2 | BKA2 | Settlements |
| Nkowinkwanta | 0602B3/H/033-1 | NN1 | Settlements |
| Asisiriwa | 0602B3/H/035-2 | ASS1 | Settlements |

The nature of activities in close proximity to boreholes or within the immediate environs of the pumps has a high tendency of contributing to the levels of contaminants in the water.

All the nineteen boreholes that were sampled in the Ejisu-Juaben district were very close to human settlements. The human activities in 50m vicinity were mainly the fetching of water. Through a personal interaction, it was observed that the local people were very cautious of the health implications that might associate their washing around the pumps.

Three of the sampled boreholes from Ejisu-Juaben were found far from settlements but close to farm lands or streets. These were the pumps at Adarko Jarchie (AJ1), Brahabebome (BBM) and Akokoamon (AM) [Table 3.1].

The boreholes were free of washing with the exception of that at Akokoamon (AM) [Table 3.1].

This was an indication that, the consumers of water from these areas were trying their best to eliminate contamination that could come from their activities.

## 3.3.0 CHEMICALS AND EQUIPMENT

### 3.3.1 Chemicals

The materials used in the project were:

- Analar grade Nitric acid manufactured by BDH Laboratory Supplies. Poole, Britain
- Analar grade Hydrochloric acid, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Ammonium chloride, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Concentrated Ammonia Solution manufactured by BDH Laboratory Supplies. Poole, Britain
- Analar grade disodium salt of Ethylenediaminetetraacetic acid, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Magnesium sulphate heptahydrate, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Erichrome black T indicator, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar Silver Nitrate, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Sodium Hydroxide, manufactured by BDH Laboratory Supplies, Poole. Britain.
- Analar grade Sulphuric acid, manufactured by BDH Laboratory Supplies, Poole. Britain.
- Analar grade anhydrous Sodium sulphate. manufactured by BDH Laboratory Supplies. Poole. Britain.

- Analar grade Glycerol, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Orthophosphoric acid, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Sodium Chloride, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Potassium dihydrogen orthophosphate, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Barium Chloride, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Chloroform, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Ascorbic acid, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade potassium antimonyl tartrate, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Sulphanilamide, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade N (-1-naphtyl) ethylene-diamine, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Sodium Nitrite, manufactured by BDH Laboratory Supplies, Poole, Britain.
- Analar grade Potassium Chloride manufactured by BDH Laboratory Supplies, Poole, Britain and

- Analar grade Potassium hydrogen phthalate from BDH Laboratory Supplies, Poole, Britain.
- Analar grade Methyl orange indicator, manufactured by Fisons Scientific Equipment, Bishop Meadow road, Loughborough.
- Analar grade Phenolphthalein indicator, manufactured by Fisons Scientific Equipment, Bishop Meadow road, Loughborough.
- Analar grade Potassium dichromate, manufactured by Fisons Scientific Equipment, Bishop Meadow road, Loughborough.
- Analar grade Sodium Carbonate manufactured by Fisons Scientific Equipment, Bishop Meadow road, Loughborough.
- Analar grade Ammonium molybdate, also manufactured by Fisons Scientific Equipment, Bishop Meadow road, Loughborough and
- Multi-element standard was also obtained from the Environmental Protection Agency, Accra, Ghana

### 3.3.2 Equipment

The equipment used in the project are as follows:

- Atomic Absorption Spectrophotometer by UNICAM, Model 969 manufactured in Offenbach, Germany.
- Suntex SP-707 pH meter manufacture in Great Lake Technology Industrial Park in Hsichih city, Taiwan.
- WTW conductivity meter manufactured in Woburn, USA, Cecil 8000 Series UV-Visible Spectrometer manufactured by Cecil Instruments, Cambridge UK.
- Lovibond Nessleriser Colour Disc manufactured in Rue de Neverlée 11 5020 Suarlée, Belgium.
- Nephla-EU, Dr – Lange Turbidimeter mnufactured in Düsseldorf, Germany.

- Jenway – PFP7 Flame Photometer manufactured in Essex, UK.

## 3.4.0 EXPERIMENTAL METHODS

The procedures that were used in the project are given below:

### 3.4.1 Treatment of Sample Containers

Sampling was done with 1L plastic containers. These were cleaned by washing with soap and tap water. The containers were left in 1+1 $HNO_3$ over night and finally rinsed with double distilled water.

The glass containers were washed by soaking in Aqua Regia (3 parts conc. HCl + 1 Part conc. $HNO_3$) and followed by a thorough wash with tap water and finally with distilled water.

### 3.4.2 Sampling

Water was pumped out of the boreholes at a very fast rate to cool the metal pipe in order to eliminate the influence of the water temperature with that of the metal pipe.

The pumping was continued for the next 5 minutes. The sample container was rinsed with some of the water and then filled to capacity and covered immediately with the lid. The cover of the container was then sealed with a masking tape.

The environmental sanitation conditions around the pumps were investigated taking into consideration the human activities around the pump area.

On-site determinations such as temperature and pH were recorded together with proper sample description (i.e. labelling) to avoid any mix-up.

Concentrated nitric acid was added to the samples meant for heavy metal analysis making the pH < 2.0. The human activities around the sample site were recorded.

### 3.4.3 Storage of Samples

All the samples were temporarily stored in a cold box at the point of sampling until they were finally transferred into a refrigerator. Samples were stored at a temperature below 4°C

### 3.4.4 pH determination

The pH meter was calibrated with 4.0, 7.0 and 10.0 pH buffers and ensured that a plot of mV versus pH followed the Nerstian relation.

A 100ml aliquot of each sample was measured into a beaker and the pH determined using a pH meter. This was done on site and at the time of the analysis in the laboratory.

### 3.4.5 Conductivity determination

The conductivity meter was standardised with 0.01N KCl solution. The conductivity of this solution was found to be 1413 at 25°C with a cell constant of 1.

A 100ml sample of water was measured into a beaker and its conductivity determined with the WTW conductivity meter within two hours of sampling. The determinations were made after refrigerated samples had been allowed to attain room temperature.

### 3.4.6 Total Dissolved Solids (TDS) Determination

A 50ml well-mixed sample was measured into a beaker.

The WTW TDS / Conductivity meter probe was immersed in sample and its conductivity recorded.

### 3.4.7 Temperature determination

This was determined on site and at the time of analysis. An aliquot of 50ml of sample was measured into a 100ml beaker and a 0 - 60°C thermometer immersed in the solution. The reading on the thermometer was then recorded.

### 3.4.8 Preparation of Reagents

1) Ammonium Chloride buffer

The buffer solution was prepared by dissolving 16.9g of ammonium chloride ($NH_4Cl$) in 143ml of conc. ammonium hydroxide solution ($NH_4OH$). This was diluted to 250ml with distilled water.

2) 0.01M Sodium salt of EDTA

A 0.01M solution of disodium salt of EDTA (Analar grade) was prepared by dissolving 3.7224g of the salt in distilled water and diluting to 1000ml. To this 780mg of magnesium sulphate heptahydrate ($MgSO_4.H_2O$) was added.

3) 0.1M HCl

A 2.1ml solution of 12M concentrated HCl was added to 200ml of distilled water in a 1000ml volumetric flask. The content of the flask was diluted with distilled water to the 1000ml mark.

4) 0.05N $Na_2CO_3$ Solution

A litre of the carbonate solution was prepared by dissolving a 4.5g of dried $Na_2CO_3$ in double distilled water and transferred into a 1L volumetric flask. The solution was made to the mark with double distilled water.

5) Standard HCl

The approximate 0.1M HCl prepared was titrated against 40ml of 0.05N $Na_2CO_3$ diluted with 60ml of water. The acid was added until a pH of 5 was reached. The solution was boiled for 5 minutes and cooled in a desiccator at room temperature. The titration was then continued to the pH inflection point.

$$N = \frac{A \times B}{53 \times C}$$

A = weight in grams of sodium carbonate

B = ml of sodium carbonate solution taken for titration

C = ml of acid used

6) 5% $K_2CrO_4$

This was prepared by weighing 5g of $K_2CrO_4$ powder. It was dissolved in a beaker of double distilled water and poured into a 100ml volumetric flask. The mixture was then diluted to the mark with double distilled water.

7) 0.01M $AgNO_3$

A one litre solution of silver nitrate was prepared by weighing 1.699g of solid silver nitrate. It was then dissolved with double distilled water in a beaker and then transferred into a 1000ml volumetric flask. It was diluted to the mark.

8) Stock Sulphate Solution

A 1.479g of anhydrous sodium sulphate salt was dissolved in double distilled water and diluted to 1000ml. This stock solution contains 1000µg / ml of sulphate.

9) Conditioning reagent

A 50ml aliquot of glycerol was mixed with a solution containing 30ml of concentrated HCl, 30ml of distilled water, 100ml 95% ethanol and 7.5g of NaCl.

10) Stock Orthophosphate solution (phosphorous solution)

Potassium dihydrogen orthophosphate was dried at 110°C. A 0.4393g of the salt was weighed and dissolved in 1L of double distilled water. The stock was preserved with 5ml of chloroform and stored in a glass stoppered flask. The strength of this stock solution is 100µg orthophosphate-phosphorus per litre.

11) 2.5M Concentrated $H_2SO_4$

An aliquot of 70ml of Analar grade concentrated $H_2SO_4$ was slowly added to 30ml of double distilled water in 500ml volumetric flask. The flask was cooled under running tap and the solution made to the mark with distilled water.

12) Ammonium molybdate solution (4%)

A weighed 40g of Analar grade ammonium molybdate was dissolved in 500ml of distilled water in a 600ml beaker. After cooling, the solution was transferred into a 1L volumetric flask and made to the mark with double distilled water. The solution was kept in a plastic bottle and stored in a refrigerator.

13) Ascorbic Acid (0.01M)

A 1.8g of Analar grade ascorbic acid was dissolved in 100ml of distilled water. This solution was prepared freshly before use. However it could be stored in a refrigerator for one week.

14) Antimony Solution (0.3%)

A 0.3g of Analar grade potassium antimonyl tartrate was dissolved in 50ml of distilled water and made up to 100ml. This solution was stored in a glass stoppered bottle.

15) Single combined Reagent

This was prepared by pouring 50ml of 2.5M $H_2SO_4$, 5ml potassium tartrate, 15ml ammonium molybdate and 30ml ascorbic acid solution.

16) Standard sodium nitrite solution

A mass of 1.232g of sodium nitrite was weighed from a previously dried amount at 100°C for 2 hours, dissolved in double distilled water and diluted to the 1000ml mark. The concentration of the standard prepared is 250μg / L N as nitrite.

17) 0.1M NaOH

An amount of 4g of sodium Hydroxide pellets was weighed. It was dissolved in a small volume of distilled water before transferring to a 100ml volumetric flask where it was diluted to the mark.

18) Colour developing reagent

A 300ml distilled water, 50ml concentrated phosphoric acid, and 7.5g of sulphanilamide ($H_2N\text{-}C_6H_4SO_4NH_2$) and 0.375g of naphthyl- 1, 1-amide were mixed together and diluted to 500ml.

19) 1000mg/L Stock Sodium solution

A stock solution of Sodium Chloride was prepared by dissolving 2.542g of NaCl in double distilled water in a 250ml beaker. The solution was then transferred into a 1 litre volumetric flask and topped to the mark.

20) 1000mg/L Stock Potassium Solution

A stock solution of Potassium Chloride was prepared by dissolving 1.907g Potassium Chloride in double distilled water in a 250ml beaker. The solution was then transferred into a 1 litre volumetric flask and topped to the mark.

21) 0.1M stock solution of potassium hydrogen phthalate was prepared in a 100ml volumetric flask by dissolving 2.04g of the salt with distilled water.

Standard solutions of concentrations of $1\text{x}10^{-3}$, $1\text{x}10^{-4}$, $2\text{x}10^{-4}$, $5\text{x}10^{-4}$ and $6\text{x}10^{-4}$M were prepared using the $M_1V_1 = M_2V_2$ relation.

### 3.4.9 Digestion of samples for Fe, Cd, Pb, Cu, Zn, Mn, K and Na determination

An aliquot of 5ml of concentrated nitric acid was added to 50ml of sample of water in a 100ml beaker. This was heated on a hotplate to boil until the colour of solution became pale and clear. The solution was heated until its volume got to about 20ml. Another 5ml of concentrated nitric acid was added and the beaker was covered with a watch glass and the heating continued for about 10 more minutes. A final 5ml acid was used to rinse the sides of the beaker. The solution was poured into a 50ml volumetric flask and topped with distilled water to the mark. A blank solution was similarly prepared. The absorbance of the blank was taken before all the analysis.

### 3.4.10 Total Hardness determination

A 50ml sample was measured into a conical flask. To this was added 1ml portion of ammonium chloride buffer solution and was then followed by the addition of 30mg erichrome black T indicator crystals. The resulting solution was titrated with 0.01M EDTA solution with continuous stirring until the end point was reached. The end point is when the last reddish tinge disappears.

Calculation: (Total hardness) mg /L $CaCO_3 = \frac{A \times B \times 1000}{\text{ml of sample}}$

Where A = ml of titrant and B = mg $CaCO_3$ equivalent to 1ml EDTA titrant.

A reagent blank without any amount of the sample was performed.

### 3.4.11 Alkalinity Determination

A 50ml sample was measured into a conical flask. Two drops of methyl orange indicator was added and the resulting mixture titrated against the standard 0.1M HCl solution to the first permanent pink colour at pH 4.5.

The following equation was used in the calculation.

Alkalinity mg $(CaCO_3)$ / L $= \frac{A \times N \times 50{,}000}{\text{ml sample}}$

Where A = ml of acid used

N = Normality of standard acid used.

A reagent blank titration was performed without the sample.

### 3.4.12 Chloride determination by Argentometric Titration

An aliquot of 50ml of sample was measured into a conical flask .The pH was then adjusted to a range of 7-10 with $H_2SO_4$ for high pH samples and NaOH for low pH samples. Two drops of $K_2CrO_4$ indicator was added.

Standard $AgNO_3$ solution of 0.01M was titrated against the resulting mixture above to a pinkish yellow end point.

A blank titration with only the reagents and no water sample was also performed.

$$\text{Chloride (mg chloride per litre)} = \frac{X \times N \times 1000 \times 35.5}{\text{ml of sample}}$$

X = end point volume

N = Normality of $AgNO_3$

### 3.4.13 Sulphate Determination

Solutions of concentration 1µg/ml, 2µg/ml, 3µg/ml and 4µg/ml were prepared. To each of these was added 10ml of conditioning reagent and 0.3g of barium chloride. The standards were allowed to stand for 45 minutes. The respective absorbances of the solutions at 420nm were determined. From this data a graph of absorbance versus concentration was plotted.

A 10ml volume of conditioning reagent was added to 25ml of sample. It was followed by the addition of 0.3g of $BaCl_2$. The mixture was then diluted to 100ml with doubled distilled water. Prepared samples were allowed to stand for 45 minutes. The concentrations were determined using the UV-Visible spectrophotometer at 420nm. A blank without $BaCl_2$ was prepared and run at the same wavelength.

### 3.4.14 Phosphate Determination by the Indirect method

Ascorbic Acid Method (Orthophosphate-Phosphorus)

Standard solutions of 1, 2, 3 and 4µg / ml were prepared. To these were added 2ml of combined reagent. The absorbance of the solutions after 10 minutes was taken at 655nm against a blank solution. A curve of absorbance versus concentration was plotted.

To 50ml of sample was added 2ml of combined reagent. The mixture was allowed to stand for 10 minutes after which the absorbance of sample was taken against a reagent blank. The concentration was obtained by comparing values with a calibration curve.

A blank analysis was performed with all the reagents without sample for all the analysis.

### 3.4.15 Colour Determination

Colour was determined within 2 hours of sampling. This was done after samples had been allowed to rest on bench to attain room temperature. An aliquot of 50ml of sample was measured into a special test tube used for colour analysis. The colour disc was rotated until a standard colour match was found for the samples.

### 3.4.16 Nitrite Determination

Aliquots of 0.1, 0.2, 0.3 and 0.4 ml of the stock solution were measured into different 100ml volumetric flasks. To these 2ml of 0.1M NaOH was added followed by the addition of 1, 2, 3 and 4ml of colour developing reagent respectively. The mixtures were diluted to 100ml mark forming 0.25 μg / ml 0.50μg / ml, 0.75μg /ml and 1.00μg/ml respectively.

A straight line graph of absorbance at 543nm versus concentration passing through the origin was obtained for the prepared standard solutions.

An aliquot of 2ml of 0.1M NaOH solution and 1ml of colour developing reagent was added to a 50ml sample. The mixture was allowed to stand for 15 to 20 minutes. The nitrite concentration was determined at wave length 543 nm of absorbance.

A blank analysis was performed with all the reagents without sample for all the analysis.

### 3.4.17 Turbidity Determination

A 30ml aliquot of each sample was measured into the cuvette of the Nephla - EU turbidimeter and the respective turbidity reading taken. This was done three times and the mean value taken.

### 3.4.18 Total Metal determination using Atomic Absorption Spectrophotometer (AAS)

The concentrations in mg/L of six metals were determined in all the samples, namely, Cu, Zn, Cd, Fe, Mn and Pb with UNICAM 969 Atomic Absorption Spectrophotometer. The flame used for the analysis was Air – Acetylene mixture.

A 100mg/L stock solution of multi-element solution was obtained from the Environmental Laboratory of the Environmental Protection Agency in Accra. Standard solutions ranging from 0.2 to 5.0mg/L were prepared for calibration curves of the various metals.

A blank analysis was performed with distilled water treated similar to the sample treatment.

The following concentrations of metal solutions were prepared to determine the Baseline Absorbance value at 4.0.

Pb: 9.4mg/L, Zn: 1.2mg/L, Cu: 3.7mg/L, Cd: 3.0mg/L, Fe: 5.5.mg/L and Mn: 2.6mg/L.

The metal concentrations were determined one after the other using their respective hollow cathode lamps (HCL) and calibration curves.

Air – Acetylene flame was used for all the analysis.

The respective wave lengths employed for the metal determinations were Fe at $\lambda_{248.7nm}$, Pb at $\lambda_{217.0nm}$, Cd at $\lambda_{228.8nm}$, Zn at $\lambda_{213.9nm}$, Mn at $\lambda_{279.5nm}$ and Cu at $\lambda_{324.8nm}$.

### 3.4.19 Na and K Determination Using Flame Emission Spectroscopy (FES)

Standard solutions of 2.0, 4.0, 6.0, 8.0 and 10.00mg/l were prepared from NaCl and KCl respectively.

The emissions of these standards were determined by aspiration into a flame photometer.

A curve of emission versus concentration was plotted and its equation determined for each element.

The same principle was applied to all the digested water samples to determine their emissions for sodium and potassium.

A blank analysis was performed with double distilled water and treated the same way as samples were treated.

The corresponding concentration values were determined with the help of the calibration curve.

The emission spectra for sodium and Potassium were determined at $\lambda_{589.0nm}$ and $\lambda_{766.5nm}$ respectively.

### 3.4.20 Organic Acid content Determination

Potassium hydrogen phthalate was used as a standard to determine the presence of all organic acids which give a similar absorbance in the UV-Visible spectrophotometric analysis.

The presence of an organic acid is characterised by an 'end' absorption within the UV-Visible region.

The standard phthalate solutions prepared were scanned on the UV-Visible spectrometer between 200-700nm. Consistent sharp end absorption was observed for all the solutions at or very close to 280nm.

A calibration curve of absorbance versus concentration at 280nm was plotted.

The organic acid concentration of the water samples were determined by determining their absorbance at 280nm.The corresponding concentrations was determined using the calibration curve plotted.

### 3.4.21 E4/E6 Determination for Samples ASS1 and OD1 all from the BAK District

- E4 is the absorbance taken at 465nm.
- E6 is the absorbance taken at 665nm.

Different volumes of 0.1M HCl and 0.1M NaOH were added to specimen from samples ASS1 and OD1 which gave considerably high concentrations of organic acid. The essence was to obtain different pH values of water specimen from these samples in the acid as well as basic range.

The absorbance values of these specimen were determined at wave lengths 465nm (E4) and 665nmn (E6) respectively.

A graph of absorbance ratio of E4/E6 was plotted against pH of the various solutions.

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

### 4.1 Results of water analysis

A total of thirty-eight boreholes were sampled. 21 from the Ejisu-Juaben and 17 from the Bosomtwi-Atwima-Kwanwoma districts of the Ashanti Region.

The samples were subject to a purely chemical analysis. The parameters that were determined were grouped under physicochemical. Anion. Cation or Trace metal and organic acid concentrations.

The physic parameters that were determined are pH. Conductivity, TDS, temperature. Colour, turbidity. hardness and alkalinity and the results have been presented in the following pages.

The anions that were determined are chloride. sulphate, phosphate and nitrite and the results have been indicated in tables 4.3 and 4.4.

The levels of Fe. Mn. Cu. Zn. Cd. Pb. Na and K in water from the two districts have been recorded in tables 4.8. 4.9. 4.16 and 4.17.

Organic matter content of samples has been given in table 4.20 and 4.21 for both districts.

Table 4.1 Physicochemical Parameters of samples from the E-J district

| Sample Name | pH | Conductivity µmhos/cm | TDS mg/L | Sampling Temperature °C | Colour /HU | Turbidity NTU | Hardness mg/l | Alkalinity mg/L |
|---|---|---|---|---|---|---|---|---|
| **AJ1** | 6.37 | 108 | 47 | 26.6 | <5 | 0.23 | 42 | 50 |
| **AJ2** | 6.19 | 201 | 86 | 27.2 | <5 | 0.27 | 53 | 45 |
| **AC3** | 3.95 | 521 | 225 | 30.2 | <5 | 0.11 | 91 | 20 |
| **AC4** | 5.14 | 103 | 44 | 31.3 | <5 | 0.21 | 56 | 30 |
| **AC2** | 4.25 | 376 | 162 | 30.3 | <5 | 0.17 | 62 | 20 |
| **AC1** | 4.26 | 573 | 246 | 31.5 | <5 | 0.19 | 88 | 10 |
| **PA1** | 7.96 | 848 | 593 | 30.3 | <5 | 1.66 | 231 | 320 |
| **AD3** | 6.85 | 105 | 46 | 30.3 | <5 | 0.20 | 104 | 100 |
| **AD2** | 6.05 | 448 | 193 | 31.3 | <5 | 0.22 | 120 | 45 |
| **AD1** | 6.65 | 482 | 208 | 30.3 | <5 | 0.21 | 163 | 100 |
| **KA1** | 6.90 | 141 | 61 | 30.3 | <5 | 0.62 | 72 | 110 |
| **KA2** | 6.60 | 251 | 108 | 30.3 | <5 | 0.35 | 62 | 100 |
| **OA1** | 6.32 | 622 | 435 | 29.3 | <5 | 0.40 | 176 | 110 |
| **BBM** | 6.09 | 224 | 157 | 30.5 | <5 | 0.81 | 77 | 220 |
| **OF** | 6.79 | 315 | 221 | 31.3 | <5 | 1.60 | 81 | 360 |
| **BM** | 5.50 | 140.3 | 98 | 30.0 | <5 | 0.36 | 40 | 180 |
| **KF** | 6.28 | 249 | 174 | 30.0 | <5 | 0.88 | 94 | 310 |
| **EJ1** | 5.10 | 153.3 | 107 | 31.0 | <5 | 0.24 | 37 | 100 |
| **PS** | 4.63 | 44.4 | 31 | 30.0 | <5 | 0.22 | 10 | 45 |
| **KA3** | 5.68 | 191.2 | 134 | 30.0 | <5 | 0.56 | 30 | 120 |
| **AM** | 5.28 | 57 | 40 | 31.2 | <5 | 0.28 | 13 | 55 |

Table 4.2 Physicochemical Parameters of samples from the BAK district

| Sample Name | pH | Conductivity µmhos/cm | TDS mg/L | Sampling Temperature °C | Colour /HU | Turbidity NTU | Hardness mg/l | Alkalinity mg/L |
|---|---|---|---|---|---|---|---|---|
| **A1** | 5.60 | 157.2 | 60.0 | 29.0 | <5 | 0.43 | 43 | 140 |
| **TA1** | 6.07 | 342.6 | 138.0 | 32.7 | <5 | **7.48** | 103 | 135 |
| **TA2** | 6.07 | 333.0 | 132.0 | 29.7 | <5 | 0.23 | 36 | 30 |
| **OD1** | 6.02 | 463.8 | 186.0 | 32.8 | **60** | **20.2** | 9 | 195 |
| **OD2** | 5.86 | 405.0 | 126.0 | 32.3 | **40** | **12.68** | 118 | 145 |
| **NKK1** | 5.29 | 192.0 | 72.0 | 33.7 | <5 | 0.18 | 25 | 55 |
| **OKK1** | 6.10 | 297.0 | 114.0 | 33.1 | 15 | **5.06** | 106 | 130 |
| **OKK2** | 6.01 | 427.2 | 168.0 | 29.5 | <5 | 0.41 | 143 | 140 |
| **AT1** | 6.01 | 187.8 | 72.0 | 31.7 | <5 | 0.36 | 42 | 35 |
| **AT2** | 6.07 | 225.0 | 90.0 | 31.7 | <5 | 0.15 | 45 | 30 |
| **AB1** | 5.49 | 101.0 | 36.0 | 32.9 | <5 | 2.40 | 23 | 35 |
| **AB2** | 5.10 | 140.4 | 54.0 | 31.5 | <5 | 0.67 | 33 | 20 |
| **KKM** | 6.74 | 671 | 469 | 29.5 | <5 | 1.26 | 294 | 210 |
| **BKA1** | 6.76 | 551 | 386 | 29.0 | <5 | 0.16 | 283 | 175 |
| **BKA2** | 6.79 | 443 | 310 | 31.1 | <5 | 0.17 | 262 | 170 |
| **NN1** | 6.65 | 843 | 590 | 31.9 | <5 | 0.16 | 3 | 365 |
| **ASS1** | 6.84 | 1114 | 779 | 20.6 | **40** | **44.95** | 402 | 170 |

### 4.2 Nature of pH of water from the Ejisu–Juaben district

The pH of the samples collected from the E-J district is represented as follows:

In the Ejisu -Juaben district the pH range of the samples analysed was 3.95-7.96 [Table 4.1] with most samples falling below the WHO standard of 6.5-8.5.

The graphical representation of the mean pH as per community shown below gives a more appreciable presentation.

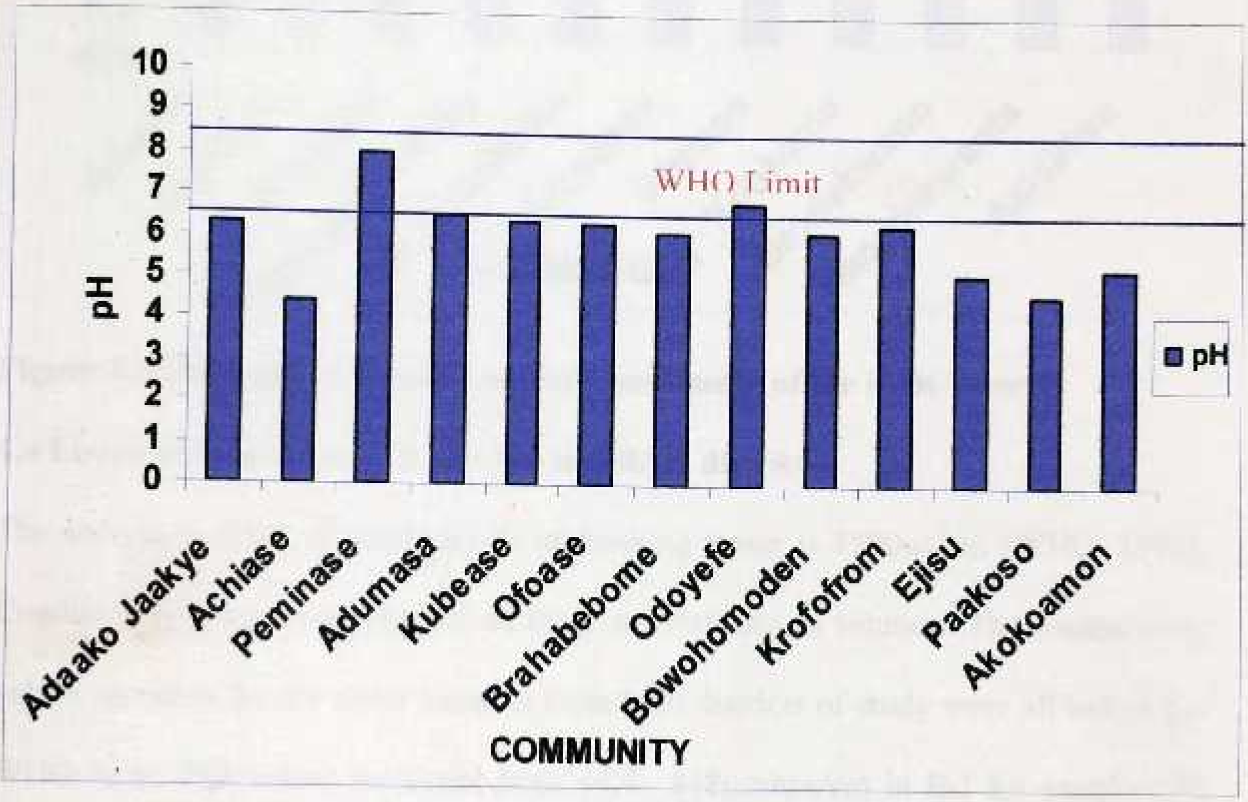


Figure 4.1 Mean pH of Sample versus Community of the Ejisu-Juaben District

### 4.3 Nature of the pH of water from BAK District

In the BAK district, the pH of all the water samples were within the GWCL permissible level >5 in the range of 5.10-6.84. The least recorded pH was 5.10 for sample ABI from Aboaso and the highest was 6.84 for sample ASS1 from Asisiriwa [Table 4.2].

Represented on the next page is a graphical summary of pH per water samples per community.

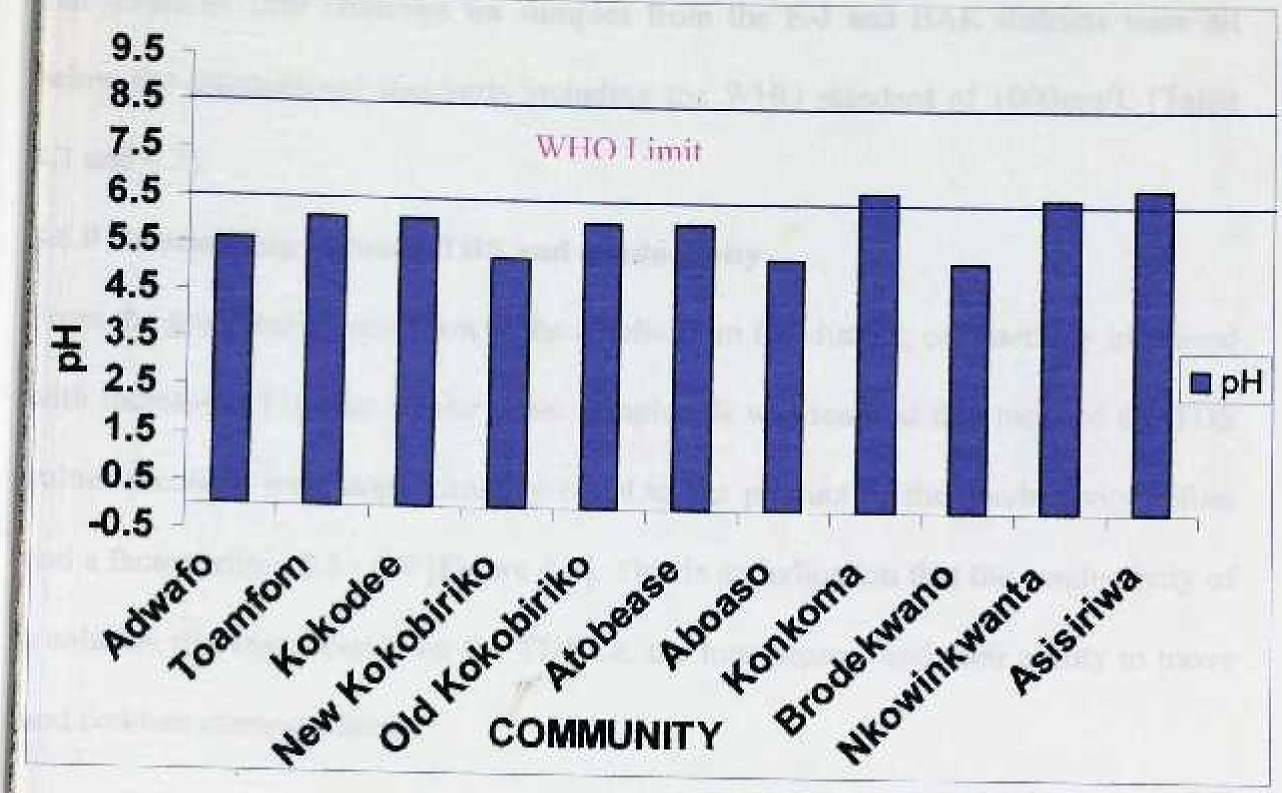


Figure 4.2 Mean pH of Samples versus Community of the BAK District

### 4.4 Levels of Conductivity in the E-J and BAK districts

The acceptable limit of conductivity of drinking water is 1500µs/cm [WHO, 1992]. Conductivity gives an account of all the dissolved ions in solution. The conductivity values recorded for the water samples from both districts of study were all below the WHO limit. The values increased from 44.4– 848µmhos/cm in E-J for samples PS and PA1 respectively [Table 4.1], while that of BAK increased from 101-1114 µmhos/cm for samples AB1 and ASS1 respectively [Table 4.2].

There were generally high values of conductivity observed for samples from BAK than for those of E-J. The low conductivity values could be attributed to lack of immobile ions in these water samples.

### 4.5 Levels of TDS in E-J and BAK districts

The TDS of water generally may not pose any health hazard but it can be aesthetically undesirable to consumers. It can also be an indication of excess organic matter present in water.

The levels of TDS observed for samples from the E-J and BAK districts were all below the international standards including the WHO standard of 1000mg/L [Table 4.1 and 4.2].

### 4.6.0 Relationship between TDS and conductivity

From the graphical presentation of the results from E-J district, conductivity increased with increasing TDS for all the water samples. It was realised that most of the TDS values recorded were approximately equal to the product of the conductivity values and a factor within 0.5 - 0.9 [Figure 4.3]. This is an indication that the conductivity of a solution directly depends on the TDS i.e. the ions present and their ability to move and conduct electric current.

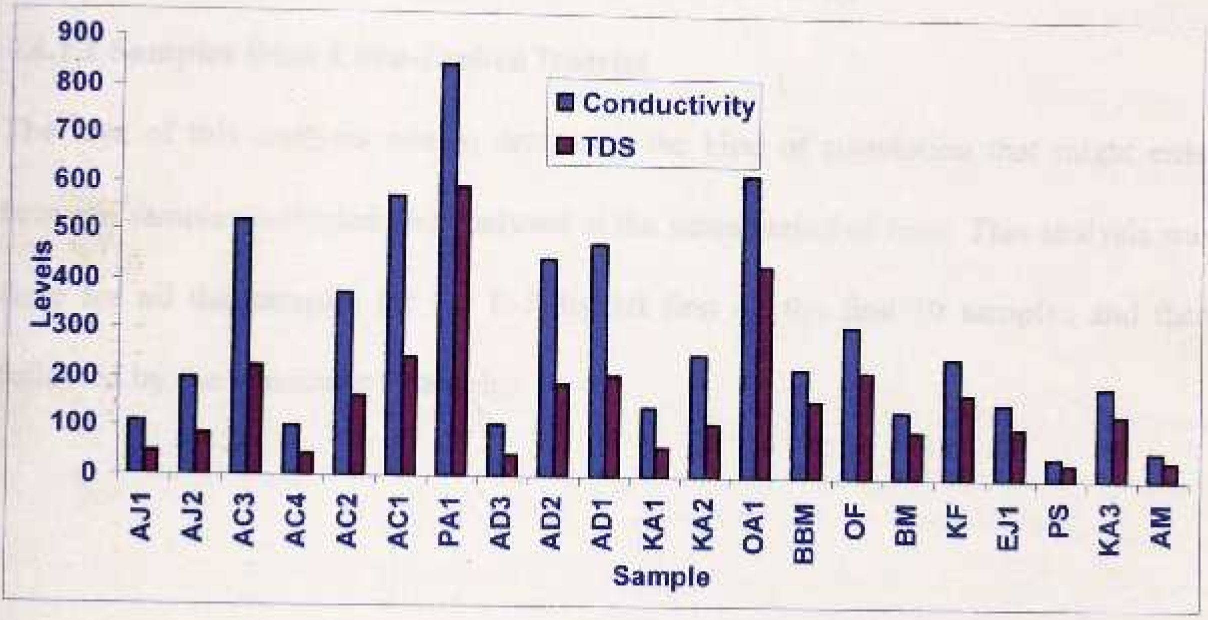


**Figure 4.3 Conductivity and TDS versus Community in the E-J district**

The same relationship observed for samples from E-J was also observed for the samples analysed from the BAK district; with sample A1 having the least TDS as well as conductivity values and ASS1 having the highest TDS and conductivity values as stated above.

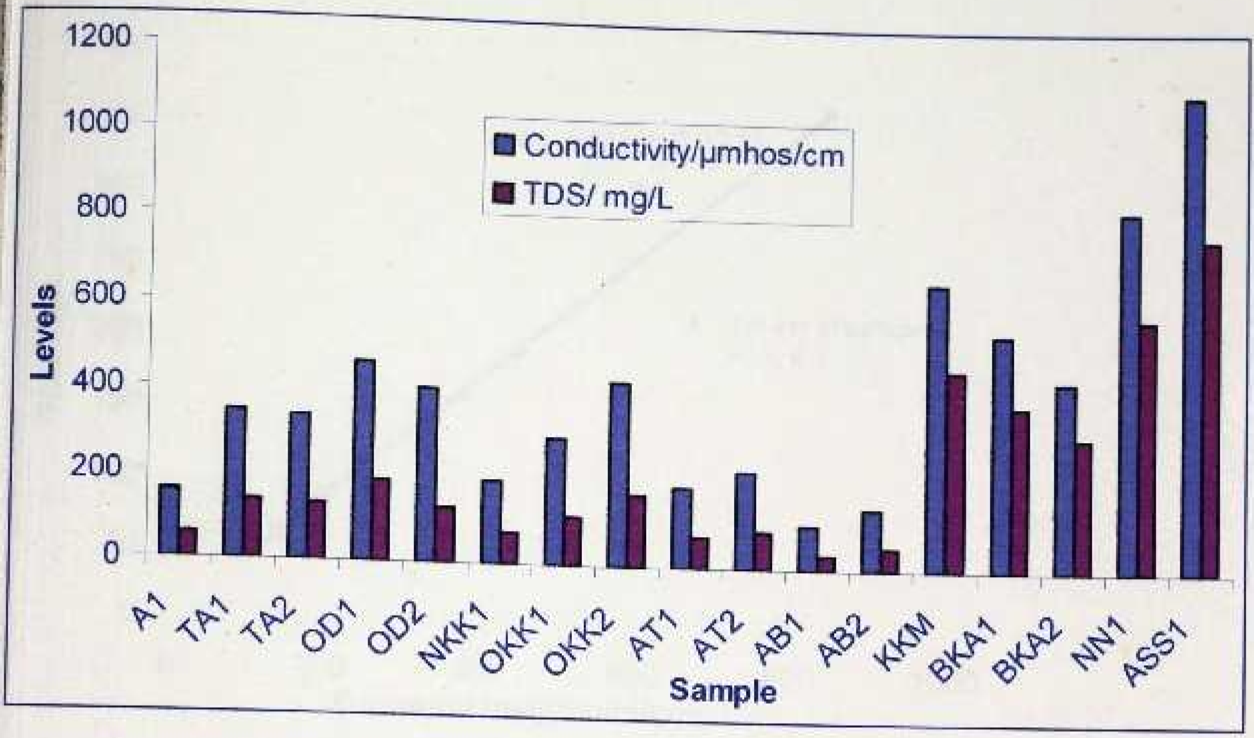


**Figure 4.4: Conductivity and TDS versus Community in the BAK district**

### 4.6.1 Linear Relationship between TDS and Conductivity

#### 4.6.1.1 Samples from Ejisu-Juaben District

The idea of this analysis was to determine the kind of correlation that might exist between samples collected and analysed at the same period of time. This analysis was done for all the samples for the E-J district first on the first 10 samples and then followed by the remaining 9 samples.

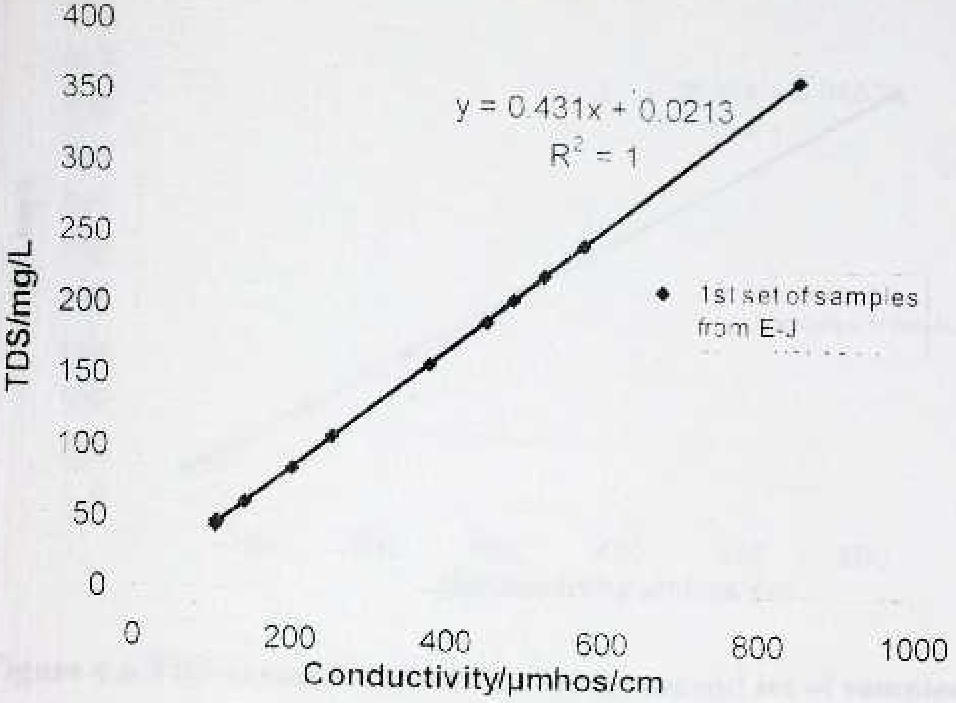


**Figure 4.5 TDS versus Conductivity for the first set of samples from E-J district**

The linear curve gave a linear correlation of $R^2$ =1 as shown in the graph above. It is a clear indication that TDS increases in a direct proportion with conductivity. Therefore when TDS is known for a water sample, the conductivity can be determined using the equation

y = 0.431x -0.0213 above [Figure 4.5].

A similar linear correlation was observed for the second set of samples as shown in Figure 4.6 with $R^2$ =1.

This is a clear indication that conductivity increases with increasing TDS. It is in fact the case since TDS, total dissolved solids increases the number of mobile ions available for electrical conductivity.

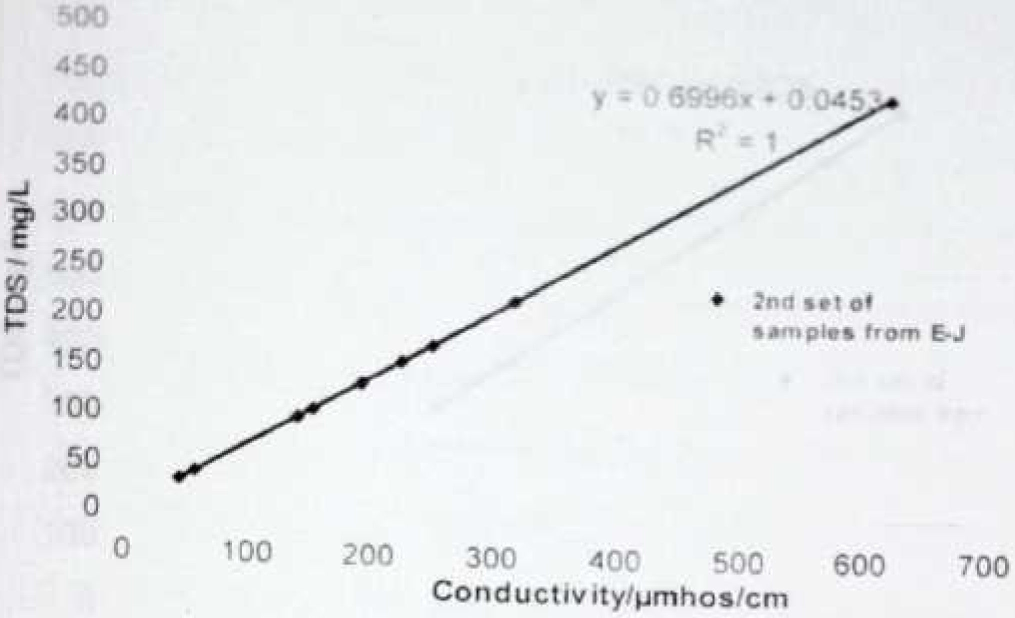


**Figure 4.6 TDS versus Conductivity for the second set of samples from E-J district**

#### 4.6.1.2 Samples from BAK District

The linear relationship between TDS and conductivity was considered for the two sets of samples from the BAK districts. The first set gave the following graphical representation of a very high correlation of $R^2 = 0.9585$ [Fig.4.7].

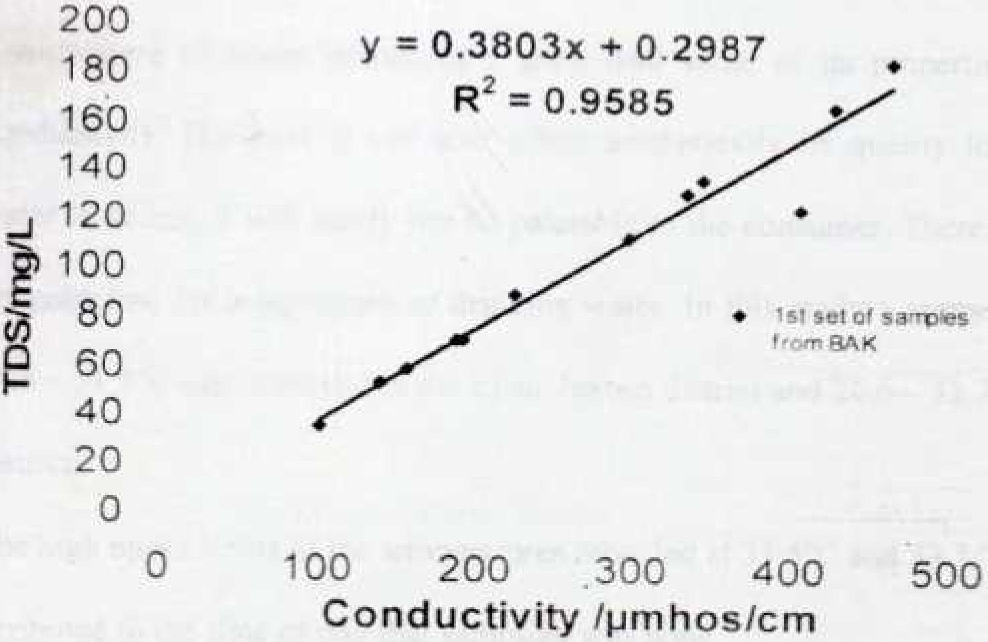


**Figure 4.7 TDS versus Conductivity for the first set of samples from BAK district**

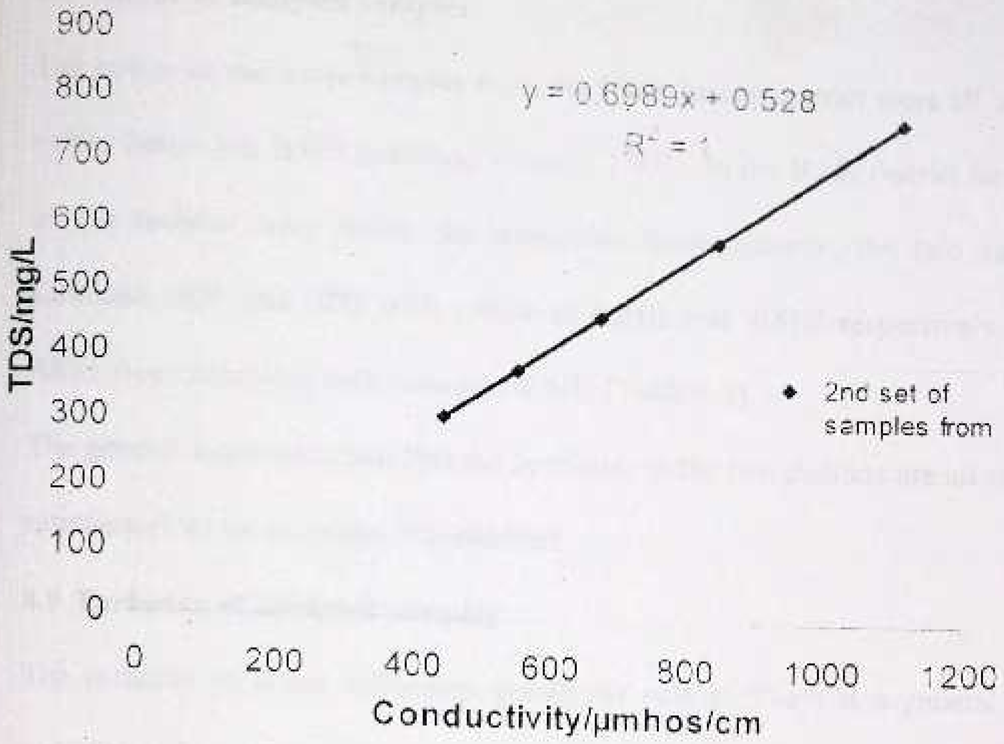


**Figure 4.8 TDS versus Conductivity for the Second set of samples from BAK district**

The figure above confirms the observations made for Fig.4.5, 4.6 and 4.7 that there is a direct correlation between TDS and conductivity.

### 4.7 Temperature of analysed samples

Temperature of water influences a great deal some of its properties like pH and conductivity. However it can also affect aesthetically its quality to consumers. If water is so hot, it will surely not be palatable to the consumer. There is generally no set guideline for temperature of drinking water. In this study a temperature range of 26.6 – 31.5°C was observed in the Ejisu-Juaben district and 20.6 – 33.7 °C in the BAK district.

The high upper limits of the temperatures recorded at 31.5°C and 33.7 °C could be attributed to the time of day that sampling was done.

These values are below the average body temperature of 37°C and therefore do not pose any health risk [Table 4.1 and 4.2].

### 4.8 Colour of analysed samples

The colour of the water samples from the Ejisu-Juaben district were all of acceptable values below the WHO guideline value of 15HU. In the BAK district however, three of the samples were below the acceptable limits namely: the two samples from Kokodee OD1 and OD2 with colour of 60HU and 40HU respectively and sample ASS1 from Asisiriwa with colour of 40HU [Table 4.2].

The general impression was that the boreholes in the two districts are all aesthetically satisfactory as far as colour is concerned.

### 4.9 Turbidity of analysed samples

The turbidity of water influences greatly its colour. There is a general increase of turbidity with increasing colour.

Considering the Ejisu-Juaben district, all samples were clear with very low turbidity values in the range of 0.11-1.66 NTU. All these values are acceptable and below the standard limit of 5.0 NTU.

On the other hand the turbidity values observed for the BAK district showed a few deviations from the standards. Samples from a community like Kokodee (OD1 and OD2), Asisiriwa (ASS1), Old Kokobiriko (OKK1) and Toamfom (TA1) were higher than the guideline value of 5.0 [Table 4.2]. These are indicated in bold font.

### 4.10 Hardness of analysed samples

Hardness of water may not have any health implications but may affect the taste of water as well as influence its lathering ability when used for washing. There was a generally acceptable hardness level of all the water samples.

The E-J district recorded the highest hardness value of 231mg/l at Peminase (PA1) and the lowest of 10mg/l at Paakoso (PS). In the BAK district however the highest value 402mg/L was recorded for Asisirwa (ASS1) and the lowest of 3mg/l Nkowinkwanta (NN1) [Table 4.1].

### 4.11 Alkalinity of analysed samples

Alkalinity measurements in water measure the total sum of all the bases that are detected by titration. The GWCL has no health guideline for alkalinity even though international organisations like the WHO and USEPA have set standards.

If one were to go by the GWCL standards, then all the water samples can be said to be safe in terms of the levels of alkalinity as measured ($CaCO_3$ in mg/L). The same would have been said when the USEPA standard of 500mg/L was being used since all the values were below 400mg/L. Even though the WHO guideline value is 200 mg/ L, samples PA1, BBM, OF, KF, KKM and NN1 with alkalinity of 320,220,360,310,210 and 365 mg/ L respectively satisfy the WHO and USEPA standard of 500mg/L.

**Table 4.3 Anion concentration of samples from the Ejisu-Juaben**

| Sample Name | Chloride mg/L | [Sulphate] µg/ml | [Phosphate-P] mg/L | [Nitrite] µg/L |
|---|---|---|---|---|
| AJ1 | 5.0 | 3.300 | 0.143 | 0.051 |
| AJ2 | 44.0 | 1.450 | 0.865 | 0.005 |
| AC3 | 66.7 | 3.700 | 0.010 | 0.008 |
| AC4 | 31.2 | 1.000 | 0.145 | 0.030 |
| AC2 | 24.1 | 1.360 | 0.002 | 0.004 |
| AC1 | 43.3 | 1.230 | 0.205 | 0.003 |
| PA1 | 38.0 | 0.650 | 1.115 | 0.001 |
| AD3 | 12.1 | 3.250 | 0.187 | 0.076 |
| AD2 | 41.2 | 0.500 | 0.054 | 0.021 |
| AD1 | 30.5 | 2.950 | 0.066 | 0.012 |
| KA1 | 14.6 | 2.600 | 0.102 | 0.009 |

| | | | | |
|---|---|---|---|---|
| **KA2** | 9.2 | 0.625 | 0.064 | 0.004 |
| **OA1** | 91.6 | 2.450 | 0.113 | 0.024 |
| **BBM** | 13.8 | 2.225 | b/d | 0.011 |
| **OF** | 13.8 | 2.200 | 0.010 | 0.007 |
| **BM** | 19.2 | 2.050 | 0.385 | 0.0009 |
| **KF** | 9.1 | 1.025 | 0.395 | 0.001 |
| **EJ1** | 14.2 | 5.875 | 0.465 | 0.006 |
| **PS** | 42.2 | 0.700 | 0.513 | 0.0024 |
| **KA3** | 26.6 | 1.350 | 0.215 | 0.006 |
| **AM** | 18.1 | 0.250 | 0.903 | 0.006 |

**Table 4.4 Anion concentration of samples from the Bosomtwi-Atwima-Kwanwoma**

| Sample Name | Chloride mg/L | [Sulphate] µg/ml | [Phosphate-P] mg/L | [Nitrite] µg/L |
|---|---|---|---|---|
| **A1** | 9.2 | 1.520 | 0.585 | 0.012 |
| **TA1** | 15.3 | 1.950 | 1.325 | 0.001 |
| **TA2** | 16.7 | 1.150 | 1.238 | 0.001 |
| **OD1** | 23.8 | 1.05 | 2.030 | b/d |
| **OD2** | 20.2 | 2.55 | 1.725 | 0.002 |
| **NKK1** | 18.1 | 2.050 | 1.100 | b/d |
| **OKK1** | 8.5 | 0.50 | 2.420 | 0.005 |
| **OKK2** | 17.8 | 1.07 | 0.855 | 0.004 |
| **AT1** | 12.1 | 1.680 | 0.645 | 0.006 |
| **AT2** | 15.3 | 2.383 | 1.263 | 0.028 |
| **AB1** | 26.3 | 1.500 | 1.583 | 0.003 |

| | | | | |
|---|---|---|---|---|
| **AB2** | 34.4 | 2.400 | 0.298 | 0.004 |
| **KKM** | 59.3 | 16.83 | 0.115 | 0.006 |
| **BKA1** | 39.7 | 11.175 | 0.038 | 0.006 |
| **BKA2** | 28.4 | 6.96 | 0.070 | 0.026 |
| **NN1** | 52.5 | 16.75 | 0.440 | 0.003 |
| **ASS1** | 60.1 | 9.450 | 0.138 | 0.003 |

### 4.12 Chloride Content of analysed samples

The presence of chlorine or chloride in drinking water has a disinfecting capability. But too much of it can be aesthetically unacceptable. This is to say that chloride impacts a salty taste to portable water. This taste is normally dependent on the chemical composition of the water. Some waters containing 250mg $Cl^-$/L may have a detectable salty taste if the Cation is sodium. On the other hand, the typical salty taste may be absent in waters containing as high as 1000mg/L chloride when the predominant cations are calcium and magnesium.

The general limit for chloride in portable water is 250mg/L. Using this figure as marker, it can be said that the entire samples were within the standard limits of GWCL, WHO etc. The chloride concentrations ranged from 5 to 91.6 mg/L in the E-J districts and 8.5 – 60.1 mg/L for samples from the BAK district [Table 4.3 and 4.4]. Chloride contents of drinking water can be influenced by the closeness of the source to the sea coast and industry.

### 4.13 Sulphate Content of analysed samples

Sulphate is present in natural water in concentrations ranging from a few to several milligrams per litre. Mine drainage wastes may contribute large amounts of sulphate

The WHO standard for sulphate in drinking water is 250mg/L. The results obtained from the turbidimetric determination of sulphate gave levels in the range of 0.25-16.83 µg/ml [Table 4.10] which are far below the limit.

The concentrations of sulphate in the water samples obtained were computed with reference to a standard curve for sulphate with equation y = 93.007X and a correlation coefficient of 1.0

In order to ascertain the reliability of the results a recovery experiment was performed and it gave the following results:

% Recovery = [(spike conc. – sample conc.) / (Expected conc. increase)] x100

**Table 4.5 Recovery of Sulphate**

| Conc. of Sulphate, µg/L | Sulphate Recovered ,µg/L | % Recovery |
|---|---|---|
| 2.0 | 1.98 | 99.0 |
| 4.0 | 4.01 | 100.3 |
| 6.0 | 5.99 | 99.8 |

The recovery analysis gave a mean% recovery of 99.7 and a standard deviation of 0.66.

## 4.14 Phosphate Content of analysed samples

Phosphates will not hurt people or animals unless they are present in very high concentrations. Even then, they will probably do little more than interfere with digestion. It is doubtful that humans or animals will encounter enough phosphate in natural waters to cause any health problems.

In order to determine the phosphate-P content of the water samples a calibration curve of absorbance versus standards was plotted for sodium phosphate. The curve had an equation of y = 14.844x.

The phosphate-phosphorous content of the water samples determined has been represented in table 4.4

The concentrations of phosphate observed in the water samples were all very low when measured in mg/L.

In the E-J district the phosphate determined fell in the range of 0.002 to 1.115mg/L while sample BBM did not give any phosphate at all.

Samples from BAK on the other hand gave a concentration range of 0.036 to 2.420mg/L for phosphate measured.

In order to determine the reliability of the results and the method used, a recovery analysis was carried out.

**Table 4.6 Recovery of Phosphate**

| Conc. of Phosphate-P, mg/L | Phosphate-P Recovered, mg/L | % Recovery |
|---|---|---|
| 0.2 | 0.199 | 99.5 |
| 0.4 | 0.398 | 99.5 |
| 1.0 | 0.997 | 99.7 |

The mean recovery obtained was 99.6% which gave a standard deviation of 0.12.

### 4.15 Nitrite Content of analysed samples

In drinking and waste water, the forms of nitrogen of greatest interest in the order of decreasing oxidation states are nitrate, nitrite, ammonia and organic nitrogen. All these forms of nitrogen as well as nitrogen gas are all biochemically interconvertible and components of the nitrogen cycle.

Nitrite is an intermediate oxidation state both for the oxidation of ammonia to nitrate and in the reduction of nitrate.

Nitrous oxide which is formed from nitrite in acidic solution can react with secondary amines to form nitrosamines, many of which are known to be casinogenic.

The nitrite content of the water samples were determined with reference to a calibration curve with an equation of $y = 2.058x$ and $R^2 = 0.9976$.

The analysis of water samples from the E-J and the BAK districts yielded results that were all lower than the guideline value 3.0mg/L.

That of the E-J districts ranged between 0.0009 and 0.076µg/L. In the case of BAK, nitrite content was below detection for two samples namely OD1 and NKK1. The rest of the samples recorded concentrations in the range of 0.001-0.028µg/L was observed [Table 4.3 and 4.4].

As a practice to check the viability of the method and results obtained, the following recovery assessment was performed.

**Table 4.7 Recovery of Nitrite**

| Conc. of Nitrite, µg/L | Nitrite Recovered ,µg/L | % Recovery |
|---|---|---|
| 0.2 | 0.202 | 101 |
| 0.5 | 0.495 | 99 |
| 1.0 | 0.992 | 99.2 |

The mean %recovery was 99.7% and the standard deviation was 1.1%.

### 4.16 Levels of Fe, Mn, Cu, Zn, Cd and Pb in samples from the E-J and BAK Districts

Trace amounts of metals are common in water, and these are normally not harmful to our health. In fact, some metals are essential to sustain life. Calcium, magnesium, potassium and sodium must be present for normal body functions. Cobalt, copper, iron, manganese, molybdenum, selenium, and zinc are needed at low levels as catalysts for enzyme activities. Drinking water containing high levels of these essential metals or toxic metals such as aluminium, arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver, may be hazardous to health [Jennings *et al.*, 1996].

Metals in water supply may occur naturally or may be the result of contamination. Naturally occurring metals are dissolved in water when it comes into contact with rock or soil material. Other sources of metal contamination are corrosion of pipes and leakage from waste disposal sites.

Iron in groundwater occurs in the form of Fe $(OH)_3$ and $Fe_2O_3$ The following buffer pairs can also exist:

$Fe^{2+} \longrightarrow Fe(OH)_3$ and $Fe^{2+} \longrightarrow Fe_2O_3$ [Drever, 1988]

The presence of iron in drinking water may increase the hazard of pathogenic organisms, since most of these organisms need iron to grow. It is known that iron influences the uptake of copper and lead. Iron in water is not a health hazard by itself but it may increase the hazard of pathogenic organisms, since many of these organisms require iron to grow.

Excess manganese in a diet prevents the use of iron in the regeneration of blood haemoglobin. Large doses of manganese cause apathy, irritability, headaches, insomnia and weakness of the legs. Psychological symptoms may also develop including impulsive acts, absent-mindedness, hallucinations, aggressiveness, and unaccountable laughter. Finally, a condition similar to Parkinson's disease may develop. Long-term heavy exposure may result in a nervous system disorder [Jennings *et al.*, 1996].

Copper deficiency causes anemia, loss of hair pigment, growth inhibition and loss of arterial elasticity. High levels of vitamin C inhibit good copper absorption. However, water containing amounts higher than 1 mg/l is likely to supply too much of this metal. One milligram per liter is also a taste threshold for the majority of people. Copper is highly toxic and very dangerous to infants and to people with certain metabolic disorders. Uptake of copper is also influenced by zinc, silver, cadmium, and sulphate in the diet. On the other hand, lack of copper intake causes anemia, growth inhibition, and blood circulation problems.

Chemically zinc is found in water in the +2 state.

Zinc is essential in the growth of living organisms. Close to two hundred zinc-containing enzymes have been identified [WHO, 1996].

Zinc containing enzymes are involved in the condensation of polymerisation of DNA and RNA and the hydrolysis of polymers during digestion of food.

In natural surface waters, the concentration of zinc is usually below 10μg/L and in groundwater 10-40μg/L [WHO, 1992].

Excess in take of zinc results in pulmonary distress, fever and chills.

Cadmium in water has similar chemical characteristics as zinc. It occurs in the +2 state. Cadmium may replace zinc in some enzymes thereby altering the stereostructure of the enzyme and impairing its catalytic effect.

Cadmium poisoning has been associated with kidney disease, hypertension, and possibly genetic mutation. Acute cadmium poisoning symptoms are similar to those of food poisoning. Up to 325mg of cadmium is not fatal but toxic symptoms occur at 10 mg. It is associated with kidney disease and linked to hypertension.

Lead can occur naturally or result from industrial contamination or be leached from lead pipes in some water systems.

Except in isolated cases lead is probably not a problem in drinking water, although the problem exists in cases where lead is used in soldering joints of pipes. Soluble $Pb^{2+}$ comes from the oxidation reaction:

$$2Pb + O_2 + 4H^+ \longrightarrow 2Pb^{2+} + 2H_2O$$

Absorption of lead increases with soft water supplies in the presence of calcium bicarbonate. This is partly due to the greater acidity of these waters which facilitate the above reaction. Lead in water can also occur as insoluble $PbCO_3$ and $PbSO_4$.

Lead is a cumulative poison and its toxicity depends on its chemical form. It is then important to be able to separate and quantify these species. Inorganic lead occurs in water in the +2 oxidation state.

Lead poisoning is difficult to distinguish in its early stages from minor illness. Early reversible symptoms include abdominal pains, decreased appetite, constipation, fatigue, sleep disturbance and decreased physical fitness. Long term exposure to lead may cause kidney damage, anaemia, and nerve damage including brain damage and finally death. Lead is a cumulative poison, meaning that it remains in the body following exposure. Children under age three are most susceptible to lead poisoning [Jennings *et al.*, 1996].

In this study Fe, Mn, Cu, Zn, Cd and Pb were analysed. The results are shown Table 4.8 and 4.9. The levels of metals above the acceptable levels have been indicated in bold font.

In the table 4.8 showing the levels of trace metals in the Ejisu-Juaben district Mn, Cu, Zn and Cd levels were all below the WHO standards of 0.5, 2.0, 3.0 and 0.003mg/L respectively.

With the exception of sample KA1 which gave an Fe concentration of 2.063mg/L, all the other samples gave levels of Fe below the guideline value of 1.0mg/L.

Sample AC1 also gave a high concentration of Mn at 1.646mg/L. This could be attributed to corrosion of the metals pumps of the boreholes.

Cu, Zn and Cd levels were all below their respective standard values but lead for all the samples were not detectable except in samples AD1 and BM at 0.0290 and 0.0215mg/L respectively.

**Table 4.8 Concentration of Trace Metals in samples from the Ejisu-Juaben District**

| **Sample ID WHO Limits** | **pH** | **Fe mg/L 1.0** | **Mn mg/L 0.5** | **Cu mg/L 2.0** | **Zn mg/L 3.0** | **Cd mg/L 0.003** | **Pb mg/L 0.01** |
|---|---|---|---|---|---|---|---|
| **AJ1** | 6.37 | 0.265 | 0.012 | 0.525 | 0.043 | 0.0018 | ND |
| **AJ2** | 6.19 | 0.314 | 0.039 | 0.193 | 0.098 | 0.0024 | ND |
| **AC3** | 3.95 | 0.191 | 0.499 | 0.715 | 0.059 | 0.0012 | ND |
| **AC4** | 5.14 | 0.080 | 0.296 | 0.619 | ND | 0.0012 | ND |
| **AC2** | 4.25 | 0.191 | 0.346 | 0.099 | ND | 0.0024 | ND |
| **AC1** | 4.26 | 0.413 | **1.646** | 0.288 | 0.153 | 0.0018 | ND |
| **PA1** | 7.96 | 0.733 | 0.088 | 0.013 | ND | 0.0018 | ND |
| **AD3** | 6.85 | 0.216 | 0.132 | 0.146 | 0.059 | ND | ND |
| **AD2** | 6.05 | 0.363 | 0.094 | 0.146 | 0.271 | 0.0030 | ND |
| **AD1** | 6.65 | 0.068 | 0.433 | 0.174 | 0.090 | 0.0024 | **0.0290** |
| **KA1** | 6.90 | **2.063** | 0.099 | 1.302 | 0.278 | 0.0030 | 0.0051 |

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| **KA2** | 6.60 | 0.302 | 0.039 | 0.146 | 0.051 | 0.0006 | ND |
| **OA1** | 6.32 | 0.634 | 0.044 | 0.174 | ND | 0.0012 | ND |
| **BBM** | 6.09 | 0.240 | 0.028 | 0.146 | 0.208 | 0.006 | ND |
| **OF** | 6.79 | 0.154 | 0.001 | 0.032 | ND | ND | ND |
| **BM** | 5.5 | 0.191 | 0.258 | 0.089 | 0.012 | 0.006 | **0.0215** |
| **KF** | 6.28 | 0.228 | 0.006 | 0.118 | ND | ND | ND |
| **EJ1** | 5.10 | 0.610 | 0.263 | 0.279 | 0.357 | 0.0012 | ND |
| **PS** | 4.63 | 0.105 | 0.033 | 0.042 | ND | 0.0030 | ND |
| **KA3** | 5.68 | 0.154 | 0.006 | 0.061 | ND | ND | ND |
| **AM** | 5.28 | 0.400 | 0.061 | 0.013 | ND | ND | ND |

- ND = Not detected

In Table 4.14 showing the levels of trace metals in the samples from BAK, the levels of Mn, Cu, Zn and Cd were all below the acceptable limits. Samples TA1, KKM and NN1 however respectively gave 1.324, 1.447, 1.817 and 3.356 mg/ L levels of Fe, which were all above the limits. Fe concentrations at these levels however will not have any health implications. The Fe levels observed in the borehole water can be attributed to depletion of metal pumps as a result of corrosion.

Mn is also a natural occurring element found in soil and finds its way into groundwater by leaching and weathering. The soluble form of manganese in water is the +2 oxidation state.

Redox reaction involving manganese occurs in groundwater as

$$MnO_2 \longrightarrow Mn^{2+}$$

In BAK the lead levels of metals were all below detection but TA2 was outstanding with lead concentration of 0.0376mg/L.

The high lead recorded for some of the samples could come from the geology of the area, contamination from sampling containers or contamination at the time of digestion. The issue of geology can be ruled out because in the case of sample AD1, two other samples namely AD2 and AD3 were collected from the same community, Adumasa. These however did not give any traces of lead in the other two samples. When sample TA2 of BAK is also considered, contamination due to geology can be ruled out since TA2 shares a similar geochemistry with TA1 whose lead concentration was below detection.

Since BM has no other sample to be compared with, the above given explanations could still hold for its high lead concentration.

**Table 4.9 Concentration of Trace Metals in samples from the BAK District**

| **Sample ID WHO Limits** | **pH** | **Fe mg/L 1.0** | **Mn mg/L 0.5** | **Cu mg/L 2.0** | **Zn mg/L 3.0** | **Cd mg/L 0.003** | **Pb mg/L 0.01** |
|---|---|---|---|---|---|---|---|
| **A1** | 5.60 | 0.055 | 0.012 | 0.013 | ND | ND | ND |
| **TA1** | 6.07 | **1.324** | 0.307 | 0.013 | 0.106 | ND | ND |
| **TA2** | 6.07 | 0.794 | 0.290 | 0.099 | 0.122 | 0.0006 | **0.0376** |
| **OD1** | 6.02 | 0.277 | **0.844** | 0.023 | ND | ND | ND |
| **OD2** | 5.86 | 0.474 | 0.351 | 0.061 | ND | ND | ND |
| **NKK1** | 5.29 | 0.265 | 0.066 | 0.070 | 0.067 | ND | ND |
| **OKK1** | 6.10 | 0.499 | 0.088 | 0.061 | 0.012 | ND | ND |
| **OKK2** | 6.01 | 0.326 | 0.088 | 0.051 | 0.027 | ND | ND |
| **AT1** | 6.01 | 0.068 | 0.001 | 0.070 | ND | ND | ND |
| **AT2** | 6.07 | 0.166 | 0.001 | 0.108 | ND | ND | ND |
| **AB1** | 5.49 | 0.240 | 0.017 | 0.061 | 0.043 | ND | ND |
| **AB2** | 5.10 | 0.277 | 0.001 | 0.032 | 0.004 | ND | ND |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **KKM** | 6.74 | **1.447** | 0.280 | 0.241 | **3.321** | 0.0026 | ND |
| **BKA1** | 6.76 | 0.474 | 0.137 | 0.336 | 0.153 | 0.0012 | ND |
| **BKA2** | 6.79 | 0.954 | 0.033 | 0.212 | ND | 0.0002 | ND |
| **NN1** | 6.65 | **1.817** | 0.066. | 0.923 | 0.459 | 0.0012 | ND |
| **ASS1** | 6.84 | **3.356** | 0.017 | 0.099 | ND | 0.0006 | ND |

- ND = Not detected

**Table 4.10 Recovery of Fe**

| Conc. of Fe, mg/L | Fe Recovered , mg/L | % Recovery |
|---|---|---|
| 0.2 | 0.190 | 95 |
| 0.5 | 0.485 | 97 |
| 1.0 | 0.960 | 96 |

Mean % Recovery = 96%, S.D = 071, %RSD = 0.71%

**Table 4.11 Recovery of Mn**

| Conc. of Mn , mg/L | Mn Recovered , mg/L | % Recovery |
|---|---|---|
| 0.2 | 0.194 | 97.0 |
| 0.5 | 0.492 | 98.4 |
| 1.0 | 0.977 | 97.7 |

Mean % Recovery = 97.7%, S.D = 0.5, %RSD = 0.5

**Table 4.12 Recovery of Cu**

| Conc. of Cu, mg/L | Cu Recovered , mg/L | % Recovery |
|---|---|---|
| 0.2 | 0.195 | 99.5 |
| 0.5 | 0.497 | 99.4 |
| 1.0 | 1.001 | 100.1 |

Mean % Recovery = 99.77%, S.D = 0.38, %RSD = 0.38

**Table 4.13 Recovery of Zn**

| Conc. of Zn , mg/L | Zn Recovered , mg/L | % Recovery |
|---|---|---|
| 0.2 | 0.198 | 99.0 |
| 0.5 | 0.499 | 99.8 |
| 1.0 | 0.997 | 99.7 |

Mean % Recovery = 99.5%, S.D = 0.31, %RSD = 0.31

**Table 4.14 Recovery of Cd**

| Conc. of Cd , mg/L | Cd Recovered , mg/L | % Recovery |
|---|---|---|
| 0.2 | 0.197 | 98.5 |
| 0.5 | 0.498 | 99.6 |
| 1.0 | 0.996 | 99.6 |

Mean % Recovery = 99.2%, S.D = 0.64, %RSD = 0.64

**Table 4.15 Recovery of Pb**

| Conc. of Pb , mg/L | Pb Recovered , mg/L | % Recovery |
|---|---|---|
| 0.2 | 0.197 | 98.5 |
| 0.5 | 0.498 | 99.6 |

| | | |
|---|---|---|
| 1.0 | 0.998 | 99.8 |

Mean % Recovery = 99.3%, S.D = 0.50, %RSD = 0.50

### 4.17 Levels of Sodium and Potassium of samples from the Ejisu-Juaben District

Sodium and potassium are nutrients which play vital roles in metabolism. They generally will not have health implications when present in water unless present in extremely high concentrations. The guideline for sodium is generally set at 200mg/L but there is no such guideline for potassium.

The fact that some patients with heart disease have difficulty in excreting sodium and are put on a low sodium diet has led to the idea that sodium is bad for the heart. However, studies show no correlation between sodium concentration and cardiovascular disease mortality. On the contrary, beneficial correlations for sodium have been reported. Areas where water is hard, highly mineralised, and also high in sodium tend to have lower cardiovascular death rates. This does not contradict the fact that in some individuals the lowering of sodium in a diet is effective in lowering the blood pressure. Depending on age, general health, and sex, sodium may present a problem in drinking water. If the sodium in water exceeds 200mg/l, it is advisable to contact the family physician for an opinion. Sodium at normal intake levels is beneficial to healthy adults. However, people with heart disease or hypertension should reduce sodium intake to lower the blood pressure [Jennings *et al.*, 1996].

The daily requirement of potassium is between 2 and 4 g. Since potassium promotes cell growth, children and young people should have an adequate intake of potassium. Potassium regulates the balance and pressure of water between the cells and ensures that the individual cells are adequately supplied with food. Potassium is of special importance for muscle contraction as well as formation and conduction of impulses of the heart. Potassium deficiency is indicated by a weakness of the skeletal musculature and tiredness of the smooth musculature. In advanced stages it can lead to intestinal paralysis and functional disorders of the heart.

The levels of sodium and potassium observed in the E-J district [Table 4.16] under observation can therefore be said to be acceptable and poses no harm to consumers for whatever purpose.

This is because the results obtained for both sodium and potassium fell below the guideline values [WHO, 2004].

**Table 4.16 Sodium and Potassium content of samples from the Ejisu-Juaben District**

| **Sample ID** | **Sodium mg/L** | **Potassium mg/L** |
|---|---|---|
| **WHO Limits** | **200** | |
| **AJ1** | 9.5 | 3.6 |
| **AJ2** | 21.1 | 8.5 |
| **AC3** | 36.7 | 14.9 |
| **AC4** | 21.1 | 5.2 |
| **AC2** | 8.3 | 6.4 |
| **AC1** | 29.7 | 67.5 |
| **PA1** | 75.7 | 3.4 |
| **AD3** | 18.7 | 0.5 |
| **AD2** | 35.9 | 1.2 |
| **AD1** | 32.8 | 14.1 |
| **KA1** | 27.33 | 2.8 |

| | | |
|---|---|---|
| **KA2** | 28.1 | 2.0 |
| **OA1** | 49.2 | 14.1 |
| **BBM** | 6.6 | 3.1 |
| **OF** | 4.5 | 3.0 |
| **BM** | 21.9 | 3.8 |
| **KF** | 7.6 | 1.0 |
| **EJ1** | 4.0 | 1.4 |
| **PS** | 5.0 | 2.4 |
| **KB3** | 13.3 | 1.3 |
| **AM** | 8.4 | 1.3 |

The E-J district gave the least sodium concentration at 4.5mg/L for sample OF and the highest 75.7 mg/L for sample PA1. In the case of potassium, the least concentration was observed for sample AD3 at 0.5mg/L and the highest by sample AC1 at 67.5 mg/L [Table 4.16].

**4.18 Levels of Sodium and Potassium of samples from the BAK District**

The level of sodium and potassium in the BAK district were not any different from that of E-J in that, they all gave values below the acceptable limits.

Sample AB1 with sodium concentration of 6.0mg/L have the least value while NN1 registered the highest value at 86.7mg/L.

The potassium content however was least at 0.2 for sample A1 and highest at 8.0 for KKM [Table 4.17].

**Table 4.17 Sodium and Potassium content of samples from the BAK District**

| Sample ID | Sodium mg/L | Potassium mg/L |
|---|---|---|
| WHO Limits | 200 | |
| A1 | 24.6 | 0.2 |
| TA1 | 26.9 | 2.3 |
| TA2 | 17.0 | 2.2 |
| OD1 | 26.9 | 0.9 |
| OD2 | 32.8 | 0.9 |
| NKK1 | 6.3 | 2.6 |
| OKK1 | 9.2 | 2.7 |
| OKK2 | 19.3 | 3.1 |
| AT1 | 8.6 | 6.9 |
| AT2 | 9.8 | 7.3 |
| AB1 | 6.0 | 2.5 |
| AB2 | 20.5 | 2.1 |
| KKM | 44.5 | 8.0 |
| BKA1 | 54.7 | 1.0 |
| BKA2 | 51.5 | 1.1 |
| NN1 | 86.7 | 2.1 |
| ASS1 | 58.6 | 5.0 |

Looking at the results from E-J and BAK, the general impression is that the water samples are rich in sodium as compared to potassium and the E-J water samples are richer in sodium and potassium than Samples from BAK.

As a way of testing the authenticity of equipment and method a recovery analysis was performed for both sodium and potassium.

Table 4.18 Recovery of Na

| Conc. of Na, mg/L | Na Recovered , mg/L | % Recovery |
|---|---|---|
| 20 | 19.0 | 95 |
| 50 | 48.0 | 96 |
| 100 | 98.0 | 98 |

Mean % Recovery = 96.3%, S.D = 1.1, %RSD = 1.1

Table 4.19 Recovery of K

| Conc. of K, mg/L | K Recovered , mg/L | % Recovery |
|---|---|---|
| 20 | 19.80 | 99.0 |
| 50 | 49.77 | 99.5 |
| 100 | 98.0 | 98.0 |

Mean % Recovery = 98.8%, S.D = 0.31, %RSD = 0.31

**Table 4.20 [Organic Acid] of Samples from the Ejisu-Juaben**

| Sample Name | Depth of B/H(m) | Organic Acid conc.(M) x10$^{-6}$ |
|---|---|---|
| AJ1 | 42 | 3.378 |
| AJ2 | 39 | 5.067 |
| AC3 | 60 | 1.266 |
| AC4 | 50 | 10.556 |
| AC2 | 45 | 8.446 |
| AC1 | 50 | 1.266 |
| PA1 | 50 | 11.823 |
| AD3 | 55 | 0.844 |
| AD2 | 55 | 8.023 |
| AD1 | 45 | 8.445 |
| KA1 | 52 | 5.911 |
| KA2 | 50 | 6.756 |
| OA1 | 60 | 17.74 |
| BBM | - | 7.389 |
| OF | - | 34.84 |
| BM | 60 | 3.378 |
| KF | - | 11.600 |
| EJ1 | - | 9.290 |
| PS | - | 5.208 |
| KB3 | - | 1.055 |
| AM | 60 | 5.911 |

**Table 4.21[Organic Acid] of samples from the BAK**

| Sample Name | Depth of B/H(m) | Organic Acid Conc.(M) x10$^{-6}$ |
|---|---|---|
| A1 | 46 | 1.266 |
| TA1 | 71 | 19.850 |
| TA2 | 70 | 26.181 |
| OD1 | 73 | 35.893 |
| OD2 | 63 | 34.626 |
| NKK1 | 61 | 11.823 |
| OKK1 | 64 | 13.512 |
| OKK2 | 55 | 13.935 |
| AT1 | 57 | 2.111 |
| AT2 | 61 | 1.266 |
| AB1 | - | 4.222 |
| AB2 | - | 8.445 |
| KKM | 49 | 6.756 |
| BKA1 | 59 | 3.589 |
| BKA2 | 40 | 0.844 |
| NN1 | 74 | 3.800 |
| ASS1 | 82 | 67.560 |

## 4.19 Organic Acid Content of samples

Organic Acid in water normally consist of humic and fulvic acids. These acids are found in very minute concentrations. Even though organic acids may not pose any health risk, they can have an influence in the aesthetic properties of drinking water in terms of impacting colour and taste to water. There is therefore no limit for its concentration in water. The concentrations of organic acid recorded for water samples analysed was in the interval of $0.844X10^{-6}$ M to $67.56X10^{-6}$ M [Table 20, 21].

This relatively high value of $67.56X10^{-6}$ M was recorded for sample ASS1 from Asisiriwa in the BAK district. The sample with the second highest concentration of organic acid was OD1 with a concentration of 35.893M also from BAK.

Coincidentally samples ASS1 and OD1 have the highest borehole depths of 82m and 73m respectively [Table 20, 21]. It would have been easy to say that organic acid concentration increases with increasing depth of borehole. But this trend is not true for all the other samples. It can safely be said that the organic acid concentration of a borehole sample does not depend on the depth of the borehole.

## 4.20 E4/E6

The absorbance of water samples at $\lambda_{465nm}$ (representing aliphatics present) and $\lambda_{665nm}$ (for aromatics) was recorded for samples that had a considerably high organic acid concentration.

The ratio of aliphatic to phenolics present in the water sample as organic carbon decreased with increasing pH for samples ASS1 and OD1.

The E4/E6 ratio for ASS1 from Asisiriwa in the BAK district decreased from 2.0 at a pH of 2.75 to 1.34 at a pH of 10.21. The results when expressed graphically as E4/E6 versus pH and it was detected that there was a general decrease of E4/E6 from low pH to high pH values [Figure 4.9].

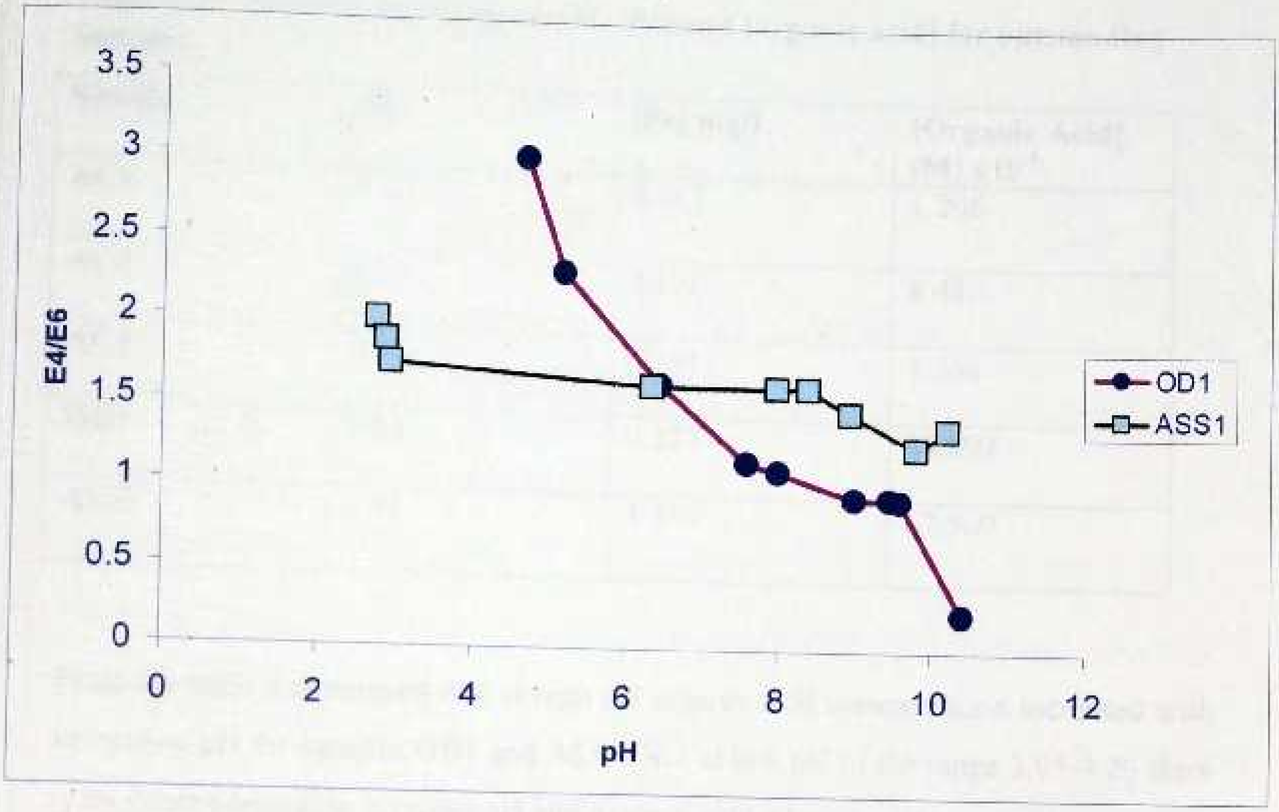


FIGURE 4.9 E4/E6 versus pH of borehole sample ASS1 and OD1

When the E4/E6 ratios for sample OD1 from Kokodee in the BAK district was determined as a function of pH, a situation similar to that observed for sample ASS1 was observed.

There was decrease of E4/E6 as a function of pH from 3.0 at pH of 4.68 to 0.23 at a pH of 10.4. A graphical representation is shown in Figure 4.9.

The trends observed in Fig.4.9 above are a clear indication that at low pH, the organic acid molecules present in the water samples have a high concentration of aliphatic functional groups than the aromatic or phenolic acid groups. This can be attributed to molecular stretching and breaking of aromatic bonds in solution.

Conversely, the concentration of phenolic acid functional groups increases with increasing pH with a decrease in the aliphatic group as a result of the molecules resistance to bond stretching or breaking.

The Fulvic acids content for organic acids are less soluble at low pH conditions but soluble at high pH.

**Table 4.22: Relationship between pH, [Fe] and [organic acid] for outstanding Samples**

| Sample | pH | [Fe] mg/L | [Organic Acid] (M) x$10^{-6}$ |
|---|---|---|---|
| **AC1** | 4.26 | 0.413 | 1.266 |
| **AC2** | 4.25 | 0.191 | 8.446 |
| **AC3** | 3.95 | 0.191 | 1.266 |
| **OD1** | 6.02 | 0.277 | 35.893 |
| **ASS1** | 6.84 | 3.356 | 67.560 |

From the table it is realised that at high pH organic acid concentration increased with increasing pH for samples OD1 and ASS1. But at low pH of the range 3.95-4.26 there is no direct correlation between pH and organic acid concentration.

The observed results are greatly affected by pH, the master parameter.

Fulvic acid does not bind to Fe at low pH. That is why the concentration of Fe for samples AC1, AC2 and AC3 do not have a direct correlation for [Fe] but does for OD1 and ASS1 at pH 6.02 and 6.84 respectively.

The metals measured in this work represent the total concentration of the respective metals. In this case it is difficult to measure the amount of a particular ion in question. This is because metals in solution normally occur as a redox ion pairs. Iron for instance is present in solution as $Fe^{3+}/Fe^{2+}$. The form of iron in solution at a point in time is dependent on pH.

# CHAPTER FIVE

## 5.0 CONCLUSION AND RECOMMENDATION

### 5.1 MAJOR FINDINGS

Though water is an indispensable tool or commodity in our fast moving industrialised world and for that matter in Ghana, its pollution has become an issue of global concern.

Since borehole water is central in the daily water consumption of the people in the two districts under study. This study has served a purpose of giving a picture of the borehole water situation in these districts.

Upon the analysis of the water samples collected from the Ejisu-Juaben and the Bosomtwi-Atwima-Kwanwoma districts and examining the resulting data, the following deductions were made:

The quality of water from the two districts in terms of the parameters determined can be said to be good in terms of:

### 5.1.1 pH

- The pH of water in the Ejisu-Juaben district ranged from 3.95-7.96 with the least value being 39.2% lower than the minimum WHO guideline value of 6.5 [Appendix 6]. This low value was recorded from sample AC3 at Achiase.
- The Bosomtwi-Atwima-Kwanwoma district gave a range of 5.10-6.84 with the least being 21.5% below the WHO lower limit.
- If acceptance of sample based on pH was to be done with the GWCL permissible guideline value of 5.0, the samples AC1, AC2, AC3 and PS from the E-J district can be said to not to be safe for drinking but can be used for other household purposes.

### 5.1.2 Conductivity and TDS

- It was observed that there was a linear relationship between the determinations of conductivity and TDS with most of the curves giving $R^2 > 0.9$.
- The values of conductivity and TDS recorded for all the districts were below the WHO guideline values. E-J had conductivity in the range of 44.4 - 848µmhos/cm and TDS in the range 31-593mg/L. BAK also gave conductivity values in the range of 101-1114 µmhos/cm and TDS of 36-779mg/L.

### 5.1.3 Temperature

- Temperature of water influences a great deal some of its properties like pH and conductivity. However it can also affect aesthetically its quality to consumers. If water is so hot, it will surely not be palatable to the consumer. There is generally no set guideline for temperature of drinking water. In this study a temperature range of 26.6 – 31.5°C was observed in the Ejisu-Juaben district and 20.6 – 33.7 °C in the BAK district.
- The high upper limits of the temperatures recorded at 31.5°C and 33.7 °C could be attributed to the time of day that sampling was done.

### 5.1.4 Colour and Turbidity

- The colour of water contributes to how appealing it will be for consumption, so does its turbidity. In this study it was observed that all the samples in the E-J district were clear with colour below 5HU. Samples OD1, OD2 and ASS1 in the BAK district gave colour values of 60, 40 and 40HU respectively which are all above the guideline value of 15HU.
- These samples can be made appealing by allowing the water to settle and decanting the top

The same can be said about the turbidity of E-J which was all within the acceptable limits in the range of 0.11-1.66 NTU. BAK registered a turbidity range of 0.15 - 44.95 NTU with sample TA1 giving 7.48, OD1 20.2, OD2 12.68, OKK1 5.06 and ASS1 44.95 NTU all above the limit of 5NTU. All the water samples can be said to be acceptable given these findings.

### 5.1.5 Hardness

- The hardness of all the samples from both the E-J and the BAK districts were all below the acceptable limits of 500mg/L.
- The highest value came from sample ASS1 in the BAK district and the least was 3mg/L also in the BAK district. In the E-J district the lowest range was 10-231mg/L.

### 5.1.6 Alkalinity

- The alkalinity of the water samples were below the WHO guideline value of 200mg/L with the exception of PA1, BBM, OF, KF, KKM and NN1 will not pose any health risks with alkalinity of 320, 220, 360, 310, 210 and 365 mg/ L respectively.
- According to the USEPA, alkalinity has no public health problem.
- The above high values therefore do not pose any problem to consumers.

### 5.1.7 Chloride

- Chloride helps in the disinfection of water from bacteria.
- All the water samples contained some chloride in concentration range of 5 to 91.6 mg/L in the E-J districts and 8.5 – 60.1 mg/L for samples from the BAK district.
- All the levels of chloride were below the WHO guideline value of 250mg/L.

### 5.1.8 Sulphate and Phosphate

- Sulphates and phosphates are nutrients that play vital role in metabolism.
- Samples were found to contain sulphate but in very low levels compared to the guideline value of 250mg/L. Phosphate has no guideline level but the levels were low.
- It can be said that the samples were not rich in these nutrients due to 0.25 - 16.83 µg/L range of sulphate observed and 0.002 to 2.420mg/L range for phosphate.

### 5.1.9 Nitrite

- Nitrite does not play any role in human metabolism but can be very harmful especially in children when it prevents the circulation of oxygen by reacting with haemoglobin.
- The levels of nitrite determined are no threat to both adult and infant life since they were all below the guideline value of 3.0mg/L.
- The levels of nitrite determined were in the range of 0.0009 to 0.076µg/L

### 5.1.10 Trace metals

- Levels of trace metals were considerably acceptable.
- Fe, Mn and Zn are all nutrients essential for the growth of the body.
- All the samples were rich in Fe, Mn and Zn metals except samples AC2, AC4, PA1, OA1,OF, KF, PS, KA3 and AM from the E-J district and A1,TA1, OD1, OD2, NKK1, OKK1, OKK2, AT1, AT2, AB1 and AB2 from the BAK district which did not have any detectable levels of Zn.

The detected levels were all below the guideline value of 3.0mg/L but BBM from the E-J district which gave Zn concentration of 3.321mg/L which is

10.7% higher than the guideline value. At this concentration zinc can be managed without causing gastrointestinal diseases.

- Fe concentration was below the WHO guideline value of 1.0mg/L except for KA1 at 2.063mg/L, TA1 at 1.324mg/L, KKM at 1.447 mg/L, NN1 at 1.817mg/L and ASS1 at 3.356mg/L. Since the forms of iron representing the total iron measured are not known, it is advised that these water samples are not used for drinking purposes but can be used for washing and other household activities.
- For manganese all the levels were within the standard value of 0.5mg/L but AC1 at 1.646mg/L and OD1 at 0.844mg/L.
- For copper and cadmium, the levels measured were all below the guideline values of 2.0mg/L and 0.003mg/L respectively for all the analyses samples.
- All the samples did not have any detectable trace of lead with the exception of TA1 which gave 0.0051mg/L of lead about 50% below the guideline value of 0.01mg/L. Samples AD1, BM and TA2 however are not recommended for drinking due to the high lead content at 0.0290, 0.0215 and 0.0376 mg/L but AD1, BM and TA2 could be used for washing.
- Samples were generally rich in sodium and Potassium.
- Concentration of sodium was in the range of 4.5 to 86.75mg/L as against the WHO guideline of 200mg/L.
- Potassium has no guideline limit, therefore the levels in the range of 0.2 to 67.55mg/L does not pose any health risk.

### 5.1.11 Organic acid and E4/E6

Organic acid concentrations were very low of the order of $10^{-6}$. The highest organic acid values were recorded for samples ASS1 and OD1 at 67.560 $X10^{-6}$ and 35.893$X10^{-6}$ respectively

- There was no correlation between organic acid and the depth of borehole.
- E4/E6 decreased generally with pH for ASS1 and OD1.

## 5.2 CONCLUSION

This work has determined the quality of water from the Ejisu-Juaben and Bosomtwi-Atwima-Kwanwoma districts chemically.

Regardless of the worry associated with very low pH values less than 5 recorded for AC1, AC2 and AC3 at Achiase as well as isolated cases of high trace metal levels, colour, turbidity and alkalinity in some of the communities, the status of the water in the Ejisu-Juaben and the Bosomtwi-Atwima-Kwanwoma Districts of Ashanti using physicochemical parameters as indicators can be said to be of acceptable quality for household utilisation.

## 5.3 RECOMMENDATIONS

Based on the outcome of the study, the following have been suggested:

The people of E-J and BAK who are the consumers of the water analysed should boil water before drinking in order to get rid of any possible microbes that might be present since no work was carried out on the level of microbial contamination.

Due to high levels of colour and turbidity, it is further suggested that the people of Toamfom, Kokodee and Asisiriwa should allow their water to stand over night before use if water is to be used for household use. This will allow the dispersed particles to settle.

The Community Water and Sanitation Agency, Districts Assemblies, NGOs and all who matter in water supply in rural communities should endeavour to organise occasional workshops for inhabitants on how to keep sanity around the catchments areas of pumps.

This will go a long way to decrease the contamination of ground water through these sources.

Stakeholders can also do the inhabitants and beneficiaries of the water they provide a lot of favour if at least an annual quality evaluation is carried out.

Providers of boreholes are also charged to conduct periodic checks in order to ensure a continued water supply.

Since this work was not able to tackle all the work that can be done as far as water in the two districts is concerned it is proposed that future work be done in the area of:

- Speciation studies to ascertain the forms and levels of the trace metals available in the water samples.
- Study on microbiological indicators of water quality in order to be fully confident of the safety of the water from the districts.
- Detailed study in the area of organic acids i.e. to extract and characterise the various functional groups present.

- Modelling on how long a contaminant gets to the groundwater, its influence and how long it stays there should be constructed for the two districts so as to make informed future analysis.

## 5.4 RELEVANCE OF THE WORK

1. This work gives a chemical as well as a scientific picture of the nature of the borehole water that the people of Ejisu-Juaben and the Bosomtwi-Atwima-Kwanwoma districts are consuming.
2. This work will also give borehole providers such as Government Agencies, NGO's and District Assemblies data on how to make informed decisions in the construction and management of boreholes.

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# APPENDICES

**Appendix 1**

**Summary of Calibration Curves**

| Analyte | Slope | Intercept | $R^2$ | n ( number of data points) |
|---|---|---|---|---|
| **Sulphate** | 93.007 | 0.0000 | 1.000 | 3 |
| **Phosphate** | 14.844 | 0.0000 | 1.000 | 3 |
| **Nitrite** | 2.058 | 0.0000 |  | 4 |
| **Potassium Hydrogen phthalate** | 2368.1 | 0.0000 | 0.996 | 5 |
| **Iron** | 0.0812 | 0.0035 | 0.995 | 3 |
| **Manganese** | 0.1826 | 0.0029 | 0.998 | 3 |
| **Copper** | 0.1055 | 0.0056 | 0.999 | 5 |
| **Cadmium** | 0.1671 | 0.0000 | 1.000 | 3 |
| **Zinc** | 0.1275 | 0.0195 | 0.997 | 3 |
| **Lead** | 0.0366 | 0.0007 | 1.000 | 3 |
| **Sodium** | 10.245 | 0.0000 | 0.994 | 5 |
| **Potassium** | 9.8571 | 5.0476 | 0.991 | 5 |

## APPENDIX 2

## PEAKS OBSERVED FOR SCANNING OF DIFFERENT CONCENTRATIONS OF POTASSIUM HYDROGEN PHTHALATE ($C_8H_5O_4K$)

| [$C_8H_5O_4K$] | Finest Peak , λ nm | Absorbance |
|---|---|---|
| $1X10^{-4}$ | 279.2 | 0.028 |
| $2X10^{-4}$ | 280.0 | 0.310 |
| $5X10^{-4}$ | 279.4 | 0.915 |
| $6X10^{-4}$ | 280.6 | 1.083 |
| $1X10^{-3}$ | 280.2 | 2.155 |

## APPENDIX 3

## ATOMIC ABSORPTION CONDITIONS FOR METALS ANALYSIS

| Parameter | Fe | Mn | Cu | Zn | Cd | Pb |
|---|---|---|---|---|---|---|
| **Lamp** | HCL | HCL | HCL | HCL | HCL | HCL |
| **Wavelength (nm)** | 248.7 | 279.5 | 324.8 | 213.9 | 228.8 | 217.0 |
| **Flame type** | Ac-Air | Ac-Air | Ac-Air | Ac-Air | Ac-Air | Ac-Air |
| **Slit Width(nm)** | 0.2 | 0.2 | 0.7 | 0.7 | 0.7 | 0.7 |
| **Lamp Current(mA)** |  | 15 |  | 15 |  | 10 |

- HCL : Hollow Cathode Lamp
- Ac-Air : Acetylene –Air

## APPENDIX 4

## EVALUATION OF pH WITH ABSORBANCE AT 465nm and 665nm RESPECTIVELY FOR SAMPLE ASS1

| pH | E4, $\lambda_{465}$ | E6, $\lambda_{665}$ | E4 / E6 |
|---|---|---|---|
| 2.75 | 0.054 | 0.027 | 2.000 |
| 2.86 | 0.062 | 0.033 | 1.879 |
| 2.94 | 0.064 | 0.037 | 1.730 |
| 6.35 | 0.068 | 0.042 | 1.619 |
| 7.98 | 0.071 | 0.045 | 1.614 |
| 8.39 | 0.071 | 0.044 | 1.614 |
| 8.94 | 0.076 | 0.052 | 1.462 |
| 9.8 | 0.100 | 0.080 | 1.250 |
| 10.21 | 0.151 | 0.110 | 1.373 |

## APPENDIX 5

### EVALUATION OF pH WITH ABSORBANCE AT 465nm and 665nm RESPECTIVELY FOR SAMPLE OD1

| pH | E4, $\lambda_{465}$ | E6, $\lambda_{665}$ | E4 / E6 |
|---|---|---|---|
| 4.68 | 0.006 | 0.002 | 3.000 |
| 5.18 | 0.014 | 0.006 | 2.300 |
| 6.45 | 0.013 | 0.008 | 1.630 |
| 7.58 | 0.011 | 0.010 | 1.150 |
| 8.00 | 0.031 | 0.033 | 1.100 |
| 8.99 | 0.061 | 0.017 | 0.940 |
| 9.45 | 0.014 | 0.060 | o.940 |
| 9.60 | 0.037 | 0.040 | 0.930 |
| 10.40 | 0.062 | 0.054 | 0.230 |

## APPENDIX 6

## GHANA WATER COMPANY LIMITED (GWCL) GUIDELINES FOR DRINKING WATER

| PARAMETER | UNITS | VALUES | PERMISIBLE LIMITS |
|---|---|---|---|
| **Turbidity** | NTU | 0-5 | |
| **colour** | HZ | 0-15 | 50 |
| **pH** | pH Units | 6.5-8.5 | >5 |
| **Electrical conductivity** | μS/cm | N/A | |
| **Total suspended solids** | mg/L | 0 | |
| **Total Dissolved solids** | mg/L | 1000 | |
| **Total Solid** | mg/L | 1000 | |
| **Sodium** | mg/L | 200 | |
| **Potassium** | mg/L | NHRG | |
| **Calcium** | mg/L | NHRG | |
| **Magnesium** | mg/L | NHRG | |
| **Iron** | mg/L | 0 -1.0 | 1.0 |
| **Copper** | mg/L | 1.0 | |
| **Zinc** | mg/L | 5.0 | |
| **Arsenic** | mg/L | 0.01 | |
| **Cadmium** | mg/L | 0.005 | |
| **Selenium** | mg/L | | |
| **Uranium** | mg/L | | |
| **Lead** | mg/L | 0.01 | |
| **Chromium** | mg/L | | |
| **Mercury** | mg/L | | |
| **Barium** | mg/L | | |
| **Nickel** | mg/L | | |
| **Boron** | mg/L | | |
| **Antimony** | mg/L | | |
| **Aluminium** | mg/L | | |
| **Manganese** | mg/L | 0- 0.1 | 0.5 |
| **Silica** | mg/L | | |
| **Hydrocarbons** | mg/L | | |
| **Total Cyanide** | mg/L | | |
| **Ammonia-N** | mg/L | 0 - 0.5 | |
| **Chloride** | mg/L | 250 | 600 |
| **Iodine** | mg/L | NAD | |
| **Fluoride** | mg/L | 1.5 | |
| **Sulphate** | mg/L | 400 | |
| **Nitrate-N** | mg/L | 0-10 | 50 |
| **Nitrite-N** | mg/L | 0-3.0 | |
| **Phosphate** | mg/L | | |
| **Alkalinity** | mg$CaCO_3$/L | | |
| **Total Hardness** | mg$CaCO_3$/L | 500 | |

- ❖ *NHRH: No health related guideline*

## APPENDIX 7

## OTHER GUIDELINES FOR DRINKING WATER QUALITY

| PARAMETER | UNIT | EU NOV.1998 | USA 1999 | WHO 2004 |
|---|---|---|---|---|
| **Turbidity** | NTU | | | 5.0 |
| **colour** | HZ | NHRG | 15 | 15 |
| **pH** | pH Units | ≥ 6.5 - ≤ 9.5 | 6.5 - 9.5 | 6.5-8.5 |
| **Elect. conductivity** | µS/cm | 2500 | | 1500 |
| **Total suspended solids** | mg/L | | | 20.0 |
| **Total Dissolved solids** | mg/L | | 500 | 1000 |
| **Total Solid** | mg/L | | | 1000 |
| **Sodium** | mg/L | 200 | | 200 |
| **Potassium** | mg/L | NHRG | NHRG | |
| **Calcium** | mg/L | NHRG | NHRG | 75 |
| **Magnesium** | mg/L | NHRG | NHRG | 30 |
| **Iron** | mg/L | 0.2 | 0.3 | 1.0 |
| **Copper** | mg/L | 2.0 | 1.0 | 2.0 |
| **Zinc** | mg/L | | 5.0 | 3.0 |
| **Arsenic** | mg/L | 0.01 | 0.05 | 0.01 |
| **Cadmium** | mg/L | 0.005 | 0.005 | 0.003 |
| **Selenium** | mg/L | 0.01 | 0.05 | 0.01 |
| **Uranium** | mg/L | | | NAD |
| **Lead** | mg/L | 0.01 | | 0.01 |
| **Chromium** | mg/L | 0.05 | 0.1 | 0.05 |
| **Mercury** | mg/L | 0.001 | 0.002 | 0.001 |
| **Barium** | mg/L | | 2.0 | 0.7 |
| **Nickel** | mg/L | 0.02 | 0.1 | 0.02 |
| **Boron** | mg/L | 0.001 | | 0.3 |
| **Beryllium** | mg/L | | 0.004 | NAD |
| **Antimony** | mg/L | 0.005 | 0.006 | 0.005 |
| **Aluminium** | mg/L | 0.2 | 0.2 | 0.2 |
| **Manganese** | mg/L | 0.05 | 0.05 | 0.5 |
| **Silica** | mg/L | | | 30 |
| **Hydrocarbons** | mg/L | | | 0.01-0.03 |
| **Total Cyanide** | mg/L | 0.05 | 0.2 | 0.07 |
| **Ammonia-N** | mg/L | | | 1.5 |
| **Chloride** | mg/L | 250 | 250 | 250 |
| **Iodine** | mg/L | | | NAD |
| **Fluoride** | mg/L | 1.5 | 4.0 | 1.5 |
| **Sulphate** | mg/L | 250 | 250 | 250 |
| **Nitrate-N** | mg/L | 50 | 10 | 50 |
| **Nitrite-N** | mg/L | 0.5 | 1.0 | 3 |
| **Phosphate** | mg/L | | | |
| **Alkalinity** | mgCaCO$_3$/L | | 500 | 200 |
| **Total Hardness** | mgCaCO$_3$/L | | 500 | 500 |

- *NHRH: No health related guideline*

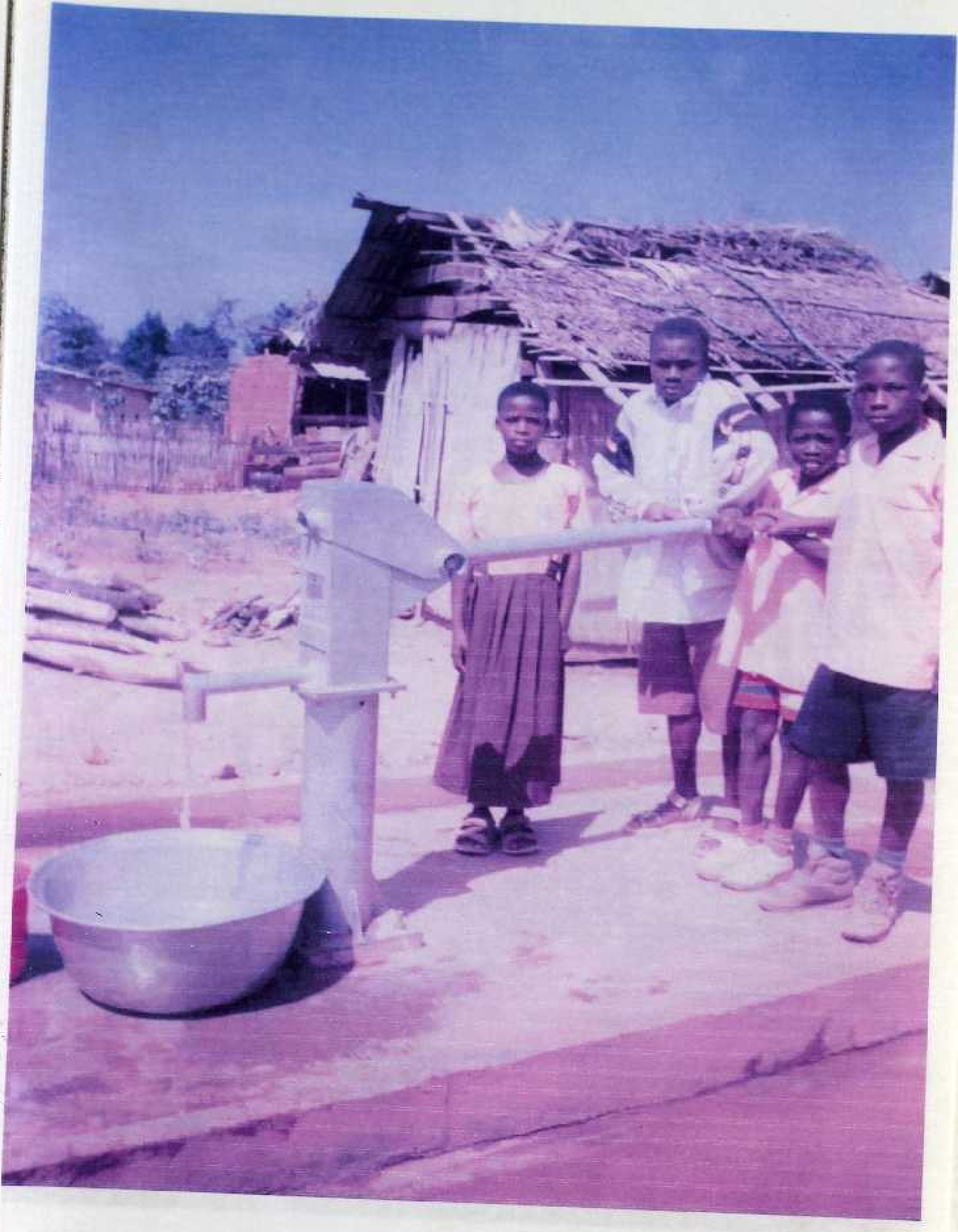
# ILLUSTRATIONS

## LIST OF ILLUSTRATIONS

### PICTURE 1

**The people of Paakoso in the Ejisu-Juaben district struggling early in the morning for their daily water**

**PICTURE 2**



Stagnant water very close to the borehole at Krofofrom in the Ejisu-Juaben district

**PICTURE 3**

Children at Paakoso who have to fetch water every morning before going to school