KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

COLLEGE OF SCIENCE

DEPARTMENT OF ENVIRONMENTAL SCIENCE

BIOLOGICAL AND PHYSICO-CHEMICAL QUALITY OF GROUND WATER AROUND THE OLD MUNICIPAL REFUSE DUMP SITE AT AHENEMA KOKOBEN

By

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A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE

BY

ABRAHAM KYEREMATENG

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DECLARATION

I hereby declare that this submission is my own work towards the M. Sc. 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 work is dedicated to my dearest wife, Mary and my kids, Mettabel and Gadwise. I also dedicate the work to my Father, Mr. Charles Kwaku Kyeremateng for supporting me throughout my education. May God richly bless you all.

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ABSTRACT

The quality of ground water from the old municipal refuse dumping site at Ahenema Kokoben in the Ashanti region was determined by taking water samples from wells and boreholes within this area. A total of thirty samples were taken from these ground water sources. Parameters such as pH, electrical conductivity (EC), salinity, dissolved oxygen (DO) and total dissolved solids (TDS) were analyzed on site, while phosphates, nitrates and sulphates in addition to heavy metals such as zinc, lead, iron and copper were analyzed in the laboratory using standard protocols. The samples were also analyzed for feacal coliform, *Escherichia coli* (*E. coli*) and *Salmonella* contamination. The DO ranged from 2.17-3.54 mg/L and pH ranging from 2.17-3.54mg/L. Phosphate and sulphates were the highest nutrient concentrations recorded with mean values ranging between 1.27-1.45 mg/L and 1.17-1.74 mg/L respectively. Contamination with Lead was found to be the high in the study area with values ranging from 0.173-0.313 mg/L, these results were above the Ghana Standards Authority (GSA) set standards for lead concentration in drinking water. *Salmonella* was not recorded in this study. However, contamination with feacal coliform and *E. coli* was recorded with a range of 3.29×10^4 -3.81×10^4 CFU/100ml and 0.94×10^2-2.03×10^2 CFU/100ml respectively. The leaching of lead into water bodies occurs during high temperatures; therefore the constant high temperatures within the study area could have been the reason for high levels of lead. Water samples from this study area were found to be unwholesome for drinking according to both the WHO and GSA standards for drinking water, due to the presence of feacal coliforms and *E. coli* and then also high concentrations of lead.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

Municipal solid waste has been a growing menace in recent times. The increase in human population has compounded the problem many fold. Waste materials or the leachates so formed during the course of time percolate to the ground water table. This may cause pollution of ground water and ultimately affect the health of the inhabitants. Leachates are formed by slow decomposition of municipal solid waste. These leachates may run off in the nearby water resources such as ponds, lakes and rivers and percolate to ground water causing pollution (Faure, 1998).

Quality drinking water is essential for life. Unfortunately, in many countries around the world, including Ghana, water has become a scarce commodity as only a small proportion of the populace has access to treated water (IDLO, 2006). Alternative sources of water such as rainwater and ground water have become major sources of drinking water for people living in new settlements and some residents who do not have access to treated water in Ghana. The assessment of the quality of water from some of these alternative sources has become imperative because they have a direct effect on the health of individuals (WHO, guidelines for drinking water quality, 2006).

Contaminants such as bacteria, viruses, heavy metals, nitrates and salt have polluted water supplies as a result of inadequate treatment and disposal of waste from humans and livestock, industrial discharges, and over-use of limited water resources (Singhl and Mosley, 2003). Even if no sources of anthropogenic contamination exist there is potential for natural levels of metals and other chemicals to be harmful to human health. This was highlighted in Bangladesh where natural levels of arsenic in groundwater were found to be causing harmful effects on the Bangladeshi population (Anawara *et al.*, 2002). Unfortunately, this problem arose because the groundwater was extracted for drinking without a detailed chemical investigation.

The natural water analyses for physical and chemical properties including trace element contents are very important for public health studies (Kot *et al*., 2000). These studies are also a main part of pollution studies in the environment.

Coliforms enter water supplies from the direct disposal of waste into streams or lakes or from runoff from wooded areas, pastures, feedlots, septic tanks, and sewage plants into streams or groundwater. Coliform can also enter an individual house via backflow of water from a contaminated source, carbon filters, or leaking well caps that allow dirt and dead organisms to fall into the water (NGA, 2008). The presence of *Escherichia coli* (*E. coli*) in drinking water denotes that the water has been faecally contaminated and therefore presents a potential health risk to households that use them untreated (WHO, 1993).

Research conducted in Ghana by Kwakye-Nuako *et al.*,(2007) indicated that 77% of filtered underground water samples sold as sachet water that were analyzed contained infective stages of pathogenic parasitic organisms. Common pathogens and indicators identified included, *Microsporidia spp*. (51.2%), *Cryptosporidium parvum* (63.0%), *Cyclosporacayetenens* (59.3%), *Sarcocystis* sp. (66.7%), Rotifers (18.5%), and Charcoat Leyden crystals (evidence of allergies or parasitic infection) (44.4%). Ninety-three percent of the samples contained unidentified impurities/artifacts. A total of 29.6% of the samples contained at least one type of parasite, 14.8% contained at least two types of parasites, 25.9% contained at least three types of parasites, and 29.6% contained four types of parasites. This has grim public health implications as the organisms identified can cause water related diseases that have serious complications in children and adults particularly immunocompromised individuals.

These factors have led to the growing rate of water borne diseases such as typhoid fever and cholera experienced in this part of the world (Edwards, 1993). The current status of access to sanitation as described by the WHO/UNICEF Joint Monitoring Programme indicates that 2.6

billion people are without improved sanitation and nearly 900 million people lack access to improved source of potable water and this situation is unacceptable (WHO/UNICEF, 2010).

With families living in poverty and local communities often left to look after themselves with none or very little assistance from overstretched or underfunded governments and local communities, a poverty trap is created that simply does not allow for investment in clean water sources and the cycle just continues (WHO/UNICEF, 2010).

1.2 JUSTIFICATION

Despite the clear benefits of improved sources of potable water for human development, many developing countries including Ghana seem to allocate insufficient resources to meet the millennium development goal (MDG) target for sanitation and potable water. There are also great inequalities in access to clean water and sanitation (UNEP, 2009). As a result of insufficient water for households by the Ghana Water Company, most households depends on hand dug wells and borehole (Ground water) for drinking water and for other purposes. The area for this study was used for the dumping of municipal solid and liquid waste from 1989 to 2004. The study area is now a residential area where the households mainly depend on hand dug wells and bole holes. It is therefore very important to analyze the quality of ground water to ascertain whether they are safe for drinking.

Moreover the water quality parameters of these communities have not been extensively studied and hence the types and levels of pollutants are unknown. The ground water quality data are thus essential for the implementation of responsible water quality regulations for characterizing and remediating contamination. It is hoped that the outcome of this work will provide policy makers with vital information to enable them act accordingly to providing potable water resources for these communities.

1.3 OBJECTIVES

1.3.1 General objective

To assess the biological and physico-chemical quality of ground water around the old municipal refuse dump site at Ahenema Kokoben in the Ashanti Region- Kumasi.

1.3.2 Specific Objectives

1. To determine the total and faecal coliforms in ground water in the study area
2. To determine the concentration of some heavy metals such as Pb, Fe, Zn and Cu, in the ground water.
3. To determine the levels of nutrients in of the ground water in the study area (Nitrates, Sulphates and Phosphates).
4. To determine the physico-chemical parameters of the ground water such as pH, DO, BOD, TDS and conductivity

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Water, the Medicine of Nature

Water is a necessity for all living beings without which there would be no life. Life originated in water and the ultimate basis of it; the protoplasm of a cell is a colloidal solution of complex organic molecules in a watery medium (70-90% water) (Krishnan, 2008). Most biological phenomena take place in a water medium and therefore wherever water exists in nature it always holds life. It is essential circulation of body fluids in plants and animals, and it stands as the key substance for the existence and continuity of life through reproduction and different cyclic processes in nature (Krishnan, 2008).

Natural water has an innate mechanism to maintain its purity after every natural use, but it is unable to do this at the rate at which humans add several pollutants and toxins flowing from industry, agriculture, domestic and other sources. Humans are bound therefore to monitor the impact of this activity on natural freshwater continuously (Krishnan, 2008).

2.2 Overview of Global Access to Drinking Water

Potable water or drinking water is water of sufficiently high quality that can be consumed or used with low risk of immediate or long term harm (APHA, 1995). Access to drinking water and improved sanitation is a fundamental need and a human right which is vital for the dignity and health of all people. The Millennium Development Goal (MDG) target -7c calls for reducing by half the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015. Reaching this target implies, tackling both the quantity (access, scarcity) and quality (safety) dimensions of drinking water provision (WHO guidelines for drinking water, 2010).

The health and economic benefits of improved water supply to households and individuals (especially children) are both indicators used to monitor progress towards the Millennium Development Goals (MDGs) (WHO/UNICEF, 2004).

The most frequently used definition of safe water accessibility is that of the United Nations Development Program (UNDP) which states that, those with access comprise the proportion of the population using any piped water, public tap, borehole with a pump, protected well and springs or rainwater (UNDP, 2002). The World Bank also provides various definitions for safe drinking water dependent on the type of residential area being assessed. In urban areas, such a source (of safe drinking water) may be a public fountain or standpoint located not more than 200 meters away and in rural areas access implies that; members of the household do not have to spend a disproportionate part of the day fetching water (World Bank Dev‘t report, 1997).

The use of improved sources of drinking water is high globally, with 87% of the world population and 84% of the people in developing regions getting their drinking water from such sources (WHO/UNICEF JMP Report, 2010). Even so, 884 million people in the world today still do not get their drinking water from improved sources; almost all of them are in developing regions. Sub-Saharan Africa accounts for over a third of that number and is lagging behind in the progress towards the Millennium Development Goal target with only 60% of the population using improved sources of drinking water despite an increase of 11% percentage points since 1990 (WHO/UNICEF JMP Report 2010).

The rural population without access to an improved drinking water resource is over five times greater than that in urban areas. Of almost 1.8 billion gaining access to improved water in the period 1990-2008, 59% live in urban areas. In urban areas, however, the increase in coverage is barely keeping pace with population growth (WHO/UNICEF JMP Report 2010).

In Ghana for instance, it is estimated that approximately 10.3 million people (51%) have access to improved water supplies and for the 8.4 million residents in the country‘s urban areas this increases slightly to 61% with two thirds of these or 40% of the total urban population covered by the Ghana Water Company Limited (GWCL) networks. The estimated rural water supply coverage is much lower at 44% (Water Aid Report, 2008).

2.3 Water Policy

The Ghana Water Company Limited is responsible for overall planning, managing and implementation of urban water supply. However, only 41.4 % of people living in the urban areas have piped water in their homes whilst 42.6% purchase water from a public tap or neighbour's residence (GOG, 2007). This shows that urban water supply by GWCL is insufficient for the urban community and there must be adjustments in policy implementation of urban water supply to ensure sustainable development as spelt out in Growth and Poverty Reduction Strategy II, New Partnership for African Development and the Millennium Development Goals, to which Ghana is signatory.

2.4 Dependence on Groundwater

Groundwater is increasingly becoming the source of drinking water for inhabitants of both rural and urban settlements due to constant water shortage which has been hitting most parts of the country. It has been estimated that lack of clean drinking water and sanitation services leads to water-related diseases globally and between five to ten million deaths occur annually, primarily of small children (Snyder and Merson, 1982). In Kumasi, the Ghana Water Company Limited (GWCL), which is mandated to provide potable water for the inhabitants of city and urban areas, is unable to supply adequate quantities due to the ever-increasing population and the inability of the government to expand the infrastructure to cater for the requirement of potable water.

Most places do not have pipelines and those who have do not have water flowing through their taps for years. This has led to the people resorting to alternative means of getting water, such as drilling wells and boreholes.

2.5. Groundwater

Groundwater occurs in many different geological formations. Nearly all rocks in the upper part of the Earth's crust possess openings called pores or voids. In unconsolidated, granular materials the voids are the spaces between the grains which may become reduced by compaction and cementation. In consolidated rocks, the only voids may be the fractures or fissures, which are generally restricted but may be enlarged by solution. The volume of water contained in the rock depends on the percentage of these openings or pores in a given volume of the rock. This is termed the porosity of the rock. More pore spaces result in higher porosity and more stored water (UNESCO/WHO/UNEP, 1996).

A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a significant quantity of water. In Ghana, a rock unit or unconsolidated medium which can yield up to 13 litres per minute constitutes an aquifer (Harvey, 2006). The limit to which soil pore spaces or fractures and voids in rock become fully saturated with water is called the water table.

The phenomenon by which water seeps down from the land surface adding to the ground water is called recharge. Ground water is recharged from rain water and snowmelt or from water that leaks through the bottom of lakes and rivers. Ground water may be obtained by drilling or digging wells and may also appear on the surface as spring. A well is usually an opening created to be able to gain access to groundwater. This may be in the form of a tube or bore lined with protective material or a shaft created by digging into the earth until the water table is reached. This water can then be brought to the land surface by a pump or a bucket and a rope. Ground water can run out 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 abstracted during these times, the water table can fall and wells may go dry.

2.6. Ground water quality

Water quality is a measure of the condition of water relative to the requirements of one or more biotic species and to any human need or purpose and it is most frequently used by reference to a set of standards against which compliance can be assessed. (Diersing- Nancy, 2009). Water quality parameters include the physical, chemical and biological characteristics of water (Appendix III).

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

Groundwater in its natural state is generally of good quality. This is because rocks and their derivatives such as soils act as filters. However, not all soils are equally effective in this respect and therefore pathogens contained in human excreta such as bacteria and viruses are likely to be small enough to be transmitted through the soil and aquifer matrix to groundwater bodies (Lewis *et al.,* 1982). Ground water can also be contaminated by surface runoff or leachate from sewage systems (Obiri-Danso *et al*., 2003).

Rainfall is a dilute chemical solution and contributes significant proportions to some constituents in groundwater, especially in regions with little soil cover where hard compact rocks occur at or near the surface. As water flows through the ground the dissolution of minerals continues and the concentration of dissolved constituents tends to increase with the length of the flow path. At great depths, where the rate of flow is extremely slow, groundwater is saline, with concentrations ranging up to ten times the salinity of the sea.

Groundwater can become unpotable if it becomes polluted and is no longer safe to drink. In areas where the material above the aquifer is permeable, pollutants can seep into groundwater. This is particularly so in a fractured aquifer.

2.7 Water pollution

Water pollution may be defined as any physical, biological or chemical change in water quality that adversely affects living organisms or makes water unsuitable for desired uses (Fei- Baffoe, 2008). Another definition indicates that, water is polluted when it contains enough foreign material to render it unfit for a specific beneficial use such as for drinking, recreation or fish propagation. (Fei- Baffoe, 2008).

Water pollution usually occurs when pollutants are discharged directly into water bodies without adequate treatment to remove harmful compounds which affects plants and other organisms living in these bodies of water and in almost all cases the effect is damaging not only to individual species and population, but also to the natural biological communities (http//environment.about.com/environmental events/waterdayqa.htm) Water pollution is a major global problem which requires ongoing evaluation and revision of water resource policy at all levels (international down to individual aquifers and wells) and has been suggested as the leading worldwide cause of deaths of more than 14,000 people daily (http/environment.about.com/environmental events/waterdayqa.htm).

Water pollutants can be classified according to the nature of origin or into groups of substances based primarily on their environmental or health effects. According to the nature of its origin, water pollutants could be classified as Point Source Pollutants (PS) or Non-point Source Pollutants (NPS). A point source is one that reaches the water from a pipe, channel or any other confined and localized source such as discharges from a sewage treatment plant, a factory or a city storm drain.

A non-point or dispersed source is broad, unconfined area from which pollutants enter a body of water; e.g. Surface run-off from agricultural areas carries silt, fertilizers, pesticides and animal waste into streams but not at one particular point (Fei-Baffoe, 2008). Other classes of water pollutants are based on their environmental or health effects and may include inorganic chemicals, organic chemicals, oxygen depleting wastes, radioactive materials and thermal pollution.

2.8 PHYSICOCHEMICAL ASSESSMENT OF WATER QUALITY

Physicochemical parameters are the physical and chemical parameters associated with water which have an influence on its quality and also affect the biological constituents of the water (Oluyemi et al., 2010). The physical factors such as temperature, colour, turbidity and conductivity can affect the aesthetics and taste of the water and may also complicate the removal of microbial pathogens during water treatment. The chemical parameters include pH, alkalinity, hardness, anions such as sulphates, phosphates, nitrates, nitrites, fluoride etc, as well as heavy metals which often tend to pose more chronic health risks through the buildup of the metals, even though some other components like nitrates, nitrites and arsenic can have a more immediate impact on consumers (http/environment.about.com/environmental events/waterdayqa.htm).

2.8.1 Colour

Colour of water is one of the most important and conveniently observed indicators of its quality. The highest quality drinking water should be colourless (WHO, 2008*)*. Potential inorganic, organic or bacteriological contributions of colour to natural water are;

(a) Inorganic constituents such as dissolved iron

(b) Dissolved organic substances like humic or fulvic acids, from anthropogenic sources such as dyes and

(c) Suspended particulate matter such as plant debris, phytoplankton and zooplanktons.

Some of these contributors may be harmless but others are definitely harmful. Suspended organic matter may itself be harmless but may harbour bacterial and viral contaminants which may be harmful to health.

Traditionally, the colours of liquids including drinking water are classified according to the Alpha/Hazen/Pt-Co colour scale (Abid *et al.*, 2005). WHO suggest that, water of colour below 15 Colour Units (CU) is acceptable to consumers although no health based guideline value is proposed for colour in drinking water.(WHO, 2008).

2.8.2 Total hardness

Water hardness is the traditional measure of the capacity of water to react with soap, with hard water requiring considerably more soap to produce lather (Neri *et al.*, 1978).

Hardness of water is not caused by a single substance but by a variety of dissolved polyvalent metallic cations mainly calcium and magnesium although other cations such as Barium, Iron, Manganese, Strontium and Zinc may also contribute. The principal natural sources of hardness in water are dissolved polyvalent metallic ions from sedimentary rocks, seepage and run-offs from soils. Ca and Mg, the two principal ions are present in many sedimentary rocks, the most common being limestone and chalk. They are also present in a wide variety of industrial products and are common constituents of food as well (McGowan, 2000). Hardness is most commonly expressed as mg/l of $CaCO_3$. Water containing less than 60mg of $CaCO_3$ per liter generally is considered as being soft. Concentrations of up to 100 mg of $CaCO_3$ per liter are fairly common in natural sources of water; whilst sources containing 200mg of $CaCO_3$ per liter are rare (McGowan, 2000).

Mg salts are soluble in water with natural sources typically containing concentrations of up to 10mg/l. Natural sources rarely contain more than 100mg of Mg per liter and it is usually Ca hardness that predominates. (National Research Council, 1997).

In drinking water, hardness is in the range of 10-500mg $CaCO_3$ per liter (Marie *et al.*, 2012). It appears there is no convincing evidence to indicate that water hardness causes adverse health effects in humans however the results of a number of epidemiological studies have suggested that there is an inverse relationship between the hardness of drinking water and cardiovascular diseases (Anderson *et al.*, 1995) but in some other studies no such association has been found. (Mackinnon *et al.*, 1980).

Depending on the interaction of other factors such as pH and alkalinity, water with hardness above approximately 200mg/l may cause scale deposition in the treatment works, distribution system and pipe work and tanks within buildings (WHO, 2008).

2.8.3 pH

pH is a measure of the acidity or alkalinity of a solution. Pure water is said to be of neutral pH which is approximately 7.0 at 25 degree Celsius. Although pH usually has no direct impact on consumers, it is one of the most operational water quality parameters (WHO, 2008). Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. For effective disinfection with chlorine, the pH should preferably be less than 8, however lower pH water is likely to be corrosive. Failure to minimize corrosion can result in the contamination of drinking water and have an adverse effect on its taste and appearance. WHO guidelines suggest that the optimum pH required in drinking water should be in the range 6.5-8.5 (WHO, 2008).

2.8.4 Conductivity

Conductivity is a measure of the ability of water to pass on or transmit an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chlorides, nitrates, sulphates, phosphate anions or sodium, magnesium, calcium, iron and aluminum cations (US EPA, 1997). Organic compounds like oil, phenol, alcohol and sugar do not conduct electrical current very well and therefore have low conductivity when in water. Conductivity is a function of temperature, types of ions present and the concentrations of the ions. The total dissolved solids (TDS) an index of conductivity, has a direct relationship to salinity and high total dissolved solids limits the suitability of water for potable use (Davis and DeWiest, 1966).

Groundwater inflows can have the same effects depending on the bedrock they flow through (Kortatsi, 2006). Conductivity is useful as a general measure of ground water quality because the water tends to have a relatively constant range of conductivity, thus once established can be used as a baseline for comparison with regular conductivity measurements (Kortatsi, 2006). Significant changes in conductivity could then be an indication that a discharge or some other sources of pollution has entered a water body.

2.8.5 NITRATES (NO^-_3) and NITRITES (NO^-_2)

Nitrates and nitrites are naturally occurring ions that are part of the nitrogen cycle. Nitrates are normally present in natural, drinking and waste waters. Nitrates enter water supplies from the breakdown of natural vegetation, the use of chemical fertilizers in modern agriculture and from the oxidation of nitrogen compounds in sewage effluents and industrial wastes.

The nitrate concentration in groundwater and surface water is normally low but can reach higher levels as a result of leaching or run-off from agricultural land or contamination from human or animal waste as a consequence of the oxidation of ammonia and similar sources (WHO, 2003).

Anaerobic conditions may result in the formation and persistence of nitrite. The formation of nitrite is as a consequence of microbial activity and may be intermittent.

The primary health concern regarding nitrate and nitrite is the formation of methaemoglobinaemia, so called blue baby syndrome. In this condition nitrate is reduced to nitrite in the stomach of infants and nitrite is able to oxidize haemoglobin (Hb) to methaemoglobin (met Hb) which is unable to transport oxygen around the body. Studies with nitrite in laboratory rats have reported hypertrophy of the adrenal zonaglomenulosa (WHO, 2003). N- Nitrosodimethylamine (NDMA) which may be produced as a by- product of industrial processes that use nitrates and/or nitrites and amines under a range of pH has also been found as a potent carcinogen in drinking water (WHO, 2002). The WHO suggests a guideline value of 50mg/l of nitrate in drinking water to protect against methaemoglobinaemia in bottle fed infants and 0.2mg/l as a provisional guideline value for nitrite. (WHO, 2008).

2.8.6 SULPHATE

Sulphates occur naturally in numerous minerals and are used commercially, especially in the chemical industry. They are discharged into water in industrial wastes and through atmospheric deposition; however the highest levels usually occur in groundwater and are from natural sources (WHO, 2008). The existing data do not identify a level of sulphate in drinking water that is likely to cause adverse human health effects. A study from a liquid diet piglet and from tap water studies with human volunteers revealed a laxative effect at concentrations of 1000-1200mg/l with no increase in diarrhoea, dehydration or weight loss, this condition is enhanced in combination with magnesium (WHO, 1984). Physiologically, consumption of large quantities of sulphur results in catharsis, dehydration, and gastrointestinal irritation. Levels of magnesium sulphate above 600mg/L in water results in purgative in adult humans, it can also result in a noticeable taste. The human body only absorbs small amounts of sulphates, but these amounts are sufficient to stimulate peristalsis by bindingmagnesium and sodium to water in the intestine. Sulphates can also lead to corrosion of distribution systems (Putz, 2003). The Ghana Standard Authority sets a recommended level of 250mg/L (Ghana Standards Board, 1998).

2.8.7 PHOSPHATE

Phosphate exists in three forms in water; orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate. Each compound contains phosphorus in a different chemical state. Organic phosphates are important in nature. Their occurrence may result from the breakdown of organic pesticides which contain phosphates. Phosphates enter water ways from human and animal wastes, phosphorus rich bedrock, industrial effluents and fertilizer runoff from agriculture. Phosphate are not toxic to people or animals unless they are present in very high levels, which could cause digestive problems. (http//www. water research.net /watershed/phosphates.htm). Phosphate occurs naturally in trace amounts in waters, and often in appreciable amounts during periods of low biological productivity. Traces of phosphate can result in algal blooms in water reservoirs (Putz, 2003). Phosphates are water treatment chemicals used to solve specific water quality problems resulting from inorganic contaminants (iron, manganese, calcium, etc.) in groundwater supplies and also to maintain water quality (inhibit corrosion, scale, biofilm, reduce lead and copper levels) in the distribution system. The guideline value for phosphate in drinking water is 400 mg/ L (WHO, 2008)

2.9 HEAVY METALS

The term heavy metal refers to any metallic chemical element that has a specific gravity that is at least five (5) times the specific gravity of water (Osei-Akoto, 2009). Specific gravity is a measure of density of a given amount of a solid substance when it is compared to an equal amount of water. Heavy metals are also toxic or poisonous at low concentrations examples include; Mercury (Hg), lead (Pb) copper(Cu), and Zinc(Zn) (http/environment.about.com/environmental events/waterdayqa.htm).

Heavy metals are natural components of the earth‘s crust but they cannot be degraded, however to a small extent they enter our bodies via food, drinking water and air. As trace elements, some heavy metals (e.g. Cu, Se, and Zn) are essential to maintain the metabolism of the human body but at higher concentrations, they can lead to poisoning. Heavy metals are dangerous because they tend to bioaccumulate; a process which results in an increase in the concentration of a chemical in a biological organism over time compared to the chemicals concentration in the environment. Heavy metals can enter a water supply by industrial and consumer waste or even from acidic rain breaking down soil and releasing the metals into streams, lakes, rivers and groundwater. (Doyle, 2006).

2.9.1 Copper

Copper is both an essential element and a drinking water contaminant. The concentration of copper in water varies widely with the primary source most often being the corrosion of interior copper plumbing. Levels in running or fully flushed water tend to be low, whereas those in standing or partially flushed water are more variable and can be substantially higher (frequently > 1mg/l). Recent studies have delineated the threshold for the effects of copper in drinking water on the gastrointestinal tract, but there is still some uncertainty regarding the long term effects of copper on sensitive populations such as carriers of the gene for Wilson disease and other metabolic disorders of copper homeostasis. (Angelova *et al.*, 2011).

2.9.2 Lead (Pb)

Lead is used principally in the production of lead –acid batteries, solder and alloys. The organolead compounds tetraethyl and tetramethyl lead have also been used extensively as antiknock and lubricating agents in petrol, although their use for these purposes in many countries is being phased out (WHO, 2008).

Owing to the decreasing use of lead containing additives in petrol and of lead containing solder in the food processing industry, concentration in air and food are declining, and intake from drinking water constitute a greater proportion of total intake (IARC, 2006).

Lead is rarely present in tap water as a result of its dissolution from natural sources; rather its presence is primarily from household plumbing systems containing lead in pipes, solder fittings or the service connections to homes.

The amount of lead dissolved from the plumbing systems depends on several facts including pH, temperature, and water hardness and standing time of the water, with soft acidic water being the most plumbo solvent. Concentrations in drinking water are generally below 5ug/l although much higher concentrations (above 100ug/litre) have been measured where lead fittings are present (Quinn and Sherlock, 1990).

Lead is a general toxicant that accumulates in the skeleton. Infants and children up to 6 years of age are most susceptible to its adverse health effects (MacKinnon and Taylor, 1980). Lead also interferes with calcium metabolism both directly and by interfering with vitamin D metabolism. Lead is toxic to both the central and peripheral nervous system, inducing supencephalopathic neurological and behavioral effects. Results from epidemiological studies also suggest that prenatal exposure to lead may have early effects on mental development that do not persist to the age of 4 years. There is also evidence from studies in humans that adverse neurotoxic effects other than cancer may occur at very low concentrations (Fewtrell *et al.,* 2003) WHO proposes a guideline value of 0.01mg/l in drinking water.

2.9.3 Iron

Iron is one of the most abundant metals in the earth crust. It is found in natural fresh waters at levels ranging from 0.5-50 mg/l. Iron may also be present in drinking water as a result of the use of iron coagulants or the corrosion of steel and cast pipes during water distribution. 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.

Iron is an essential element in human nutrition. It helps transport oxygen in the blood. Estimates of the minimum daily requirement for iron depends on age, sex, physiological status and iron bio availability and range from about 10 to 50mg/day (Wolfhard and Reinhard, 1998). Iron is not hazardous to health, but it is considered a secondary or aesthetic contaminant.

2.9.4 Zinc

Zinc is a very common substance that occurs naturally. Many foodstuffs contain certain concentrations of zinc. Drinking water also contain certain amounts of zinc which may be higher when it is stored in metal tanks, however zinc concentrations are rising unnaturally due to addition of zinc through human activities (http/environment.about.com/environmental events/waterdayqa.htm). Some soils are heavily contaminated with zinc and these are found in areas where zinc is mined or refined or where zinc sewage sludge is used as fertilizer. In natural surface waters, the concentration of zinc is usually below 10μg/l and in groundwater‘s; 10 - 40μg/l (Nriagu, 1980).Food poisoning attributable to the use of galvanized zinc containers in food preparation has been reported; a situation in which symptoms occurred within 24hrs and included nausea, vomiting and diarrhea accompanied by bleeding and abdominal cramp (Elinder, 1986). Drinking water containing zinc at levels above 3mg/l tends to be opalescent, develops a greasy film when boiled and has an undesirable taste (Bruvold and Ongerth, 1996).

2.10. Bacteriological hazards associated with drinking water

The greatest risk from microbes in water is associated with consumption of drinking water that is contaminated with human excreta, although other sources and routes of exposure may also be significant (WHO, 2008). Infectious diseases caused by pathogenic bacteria, viruses and parasites (e.g. protozoa and helminthes) are the most common and widespread health risks associated with drinking water. Some of these pathogens that are known to be transmitted through contaminated drinking water lead to severe and sometimes life threatening diseases like typhoid, cholera, infectious hepatitis (caused by A virus (HAV or HEV)) and diseases caused by *Shigella spp and E- coli O157*. Others are typically associated with less severe outcomes such as self-limiting diarrheal disease e.g.; *Norovirus* and *Cryptosporidium.* The number of known pathogens for which water is a transmission route continue to increase as new or previously unrecognized pathogens continue to be discovered (WHO, 2003).

2.10.1 Indicator Organisms

Indicator organisms are used to measure potential feacal contamination in water. In water quality analysis it may be possible to isolate microbial pathogens from contaminated water especially when it is heavily polluted, however large volumes (several litres) of the water may be required, selective media are required for isolation and the subsequent identification of the organisms involves biochemical, serological and other tests on pure cultures. Reliance is therefore placed on relatively simple and more rapid bacteriological tests for the detection of certain commensal intestinal bacteria (especially E. coli and other coliform bacteria) as indicator organisms. This is because they are easier to isolate and characterize and also present always in feaces of man and warm blooded animals and hence in sewage in large numbers. The presence of such feacal indicator organisms in a sample of drinking water thus denotes that intestinal pathogens could be present, and that the supply is therefore potentially dangerous to health (Berg, 1978).

2.10.2 Faecal coliforms

A feacal coliform is a facultative anaerobic rod shaped gram negative, non sporulating bacterium. Feacal coliform are capable of growth in the presence of bile salts or similar agents, are oxidase negative and produce acid and gas from lactose within 48hrs at 44+ 0.50 degree Celsius (Doyle and Erickson, 2006).

The presence of faecal coliform bacteria in aquatic environments indicates that the water has been contaminated with a feacal material of man or animals. Feacal coliform bacteria can enter drinking waters through direct discharge of waste from mammals and birds, from agricultural and storm runoff and from untreated human sewage. Individual home septic tanks can become overloaded during the rainy season and allow untreated human waste to flow into drainage ditches and into groundwater.

Agricultural practices such as allowing animal wastes to wash into nearby streams during the rainy season, spreading manure and fertilizer on fields during rainy periods and allowing livestock watering in streams can all contribute to feacal coliform contamination. Feacal coliform bacteria do not directly cause diseases, but high quantities suggest the presence of disease causing agents. Feacal coliforms like other bacteria can usually be killed by boiling water or treating with chlorine. Washing thoroughly with soap after contact with contaminated water can also help prevent infections.

2.10.3 Escherichia coli

Escherichia coli (commonly abbreviated *E. coli*) is a gram negative rod shaped bacterium that is commonly found in the lower intestines of warm blooded organisms. *E. coli* and related bacteria constitute about 0.1% of gut flora (Eckburb *et al.,* 2005) and faecal oral transmission is the major route through which pathogenic strains of the bacterium cause diseases. Cells are able to survive outside the body for a limited amount of time which makes them ideal organisms to test environmental samples for faecal contamination. *E. coli* can be differentiated from other thermotorelant coliforms by the ability to produce indole from typtophan or by the production of the enzyme β-glucuronidase.

E. coli is present in very high numbers in human and animal faeces and is rarely found in the absence of faecal pollution. It is considered the most suitable index of faecal contamination and as such it is the first organism of choice in monitoring programmes for verification, including surveillance of drinking water quality (Ashbolt *et al.,* 2001). Water temperatures and nutrient conditions present in potable water distribution systems are highly unlikely to support the growth of these organisms (Grabow, 1996).

2.10.4 Salmonella

Salmonella spp. belongs to the family of enterobacteriaceae. They are motile gram negative bacilli that do not ferment lactose but most produce hydrogen gas from carbohydrate fermentation (Clark, 1987) Common species include *Salmonella enteric* or *Salmonella cholaesius*, *Salmonella bongori* and *Salmonella typhi*. All of the enteric pathogens except *S. typhi* are members of the species of *Salmonella enterica*.

Salmonella infections typically are zoonotic and can be transferred between humans and non-human animals. The pathogens typically gain entry into water systems through feacal contamination from sewage discharges, livestock and wild animals. Salmonella can survive for weeks outside a living body and are not destroyed by freezing. However UV-radiation and heat accelerate their demise (Sorrells *et al.,* 1970).

Salmonella infections cause four clinical manifestations: gastroenteritis (ranging from mild to fulminant diarrhoea, nausea and vomiting) bacteraemia or septicaemia (high spiking fever with positive blood cultures), typhoid fever enteric fever sustained fever with or without diarrhoea) and a carrier state in persons with previous infections (Angulo *et al.*, 1997). Typhoid fever is a more severe illness and can be fatal. Over 16 million people worldwide are infected with typhoid fever each year with 500,000 to 600,000 fatal cases (WHO, 2003).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The study was carried out at the old municipal solid waste dump site at Ahenema Kokoben in the Atwima Kwanwoma District of the Ashanti Region. Ahenema Kokoben is located at around 6km from Kejetia off Obuasi road. The District is located on latitude 6 24″N and 6 43` North and longitude 1 15′ and 1 46″ West. The district is located in the central portion of the Ashanti region, bordered in the North by Kumasi Metropolitan Assembly, South by Amensie West District, east by Bosomtwi District and west by Atwima Nwabiagya District. The district has a total land size of 340.9km constituting 1.4% of the total land area of Ashanti Region.

The climate of the district is wet semi – equatorial type. The mean monthly temperature is about 20^{o}C. A maximum temperature of about 28^{o}C is recorded in March and April just before the onset of the rainy season. The rainfall pattern consists of two (2) rainy seasons. The major season is usually between March and July with June as the peak period. The minor season is between late September and November.

The mean annual rainfall ranges from 140 – 170 cm. Rainfall totals and incidence vary widely from year to year. The number of rainy days average about 100 – 120 days per year with 75% of this occurring during the major season (MOFA, 2013). The months of December through March are virtually dry. The relative humidity is high especially in the rainy season and early mornings. The climate change has actually altered this climatic pattern such that one cannot determine the known patterns with accuracy. This actually affects farming activities, the major economic activity in the district. This is so because the farming activity in the district like any other part of Ghana is climate dependent (MOFA, 2013).

A MAP SHOWING THE PROJECT AREA AND THE SAMPLING POINTS

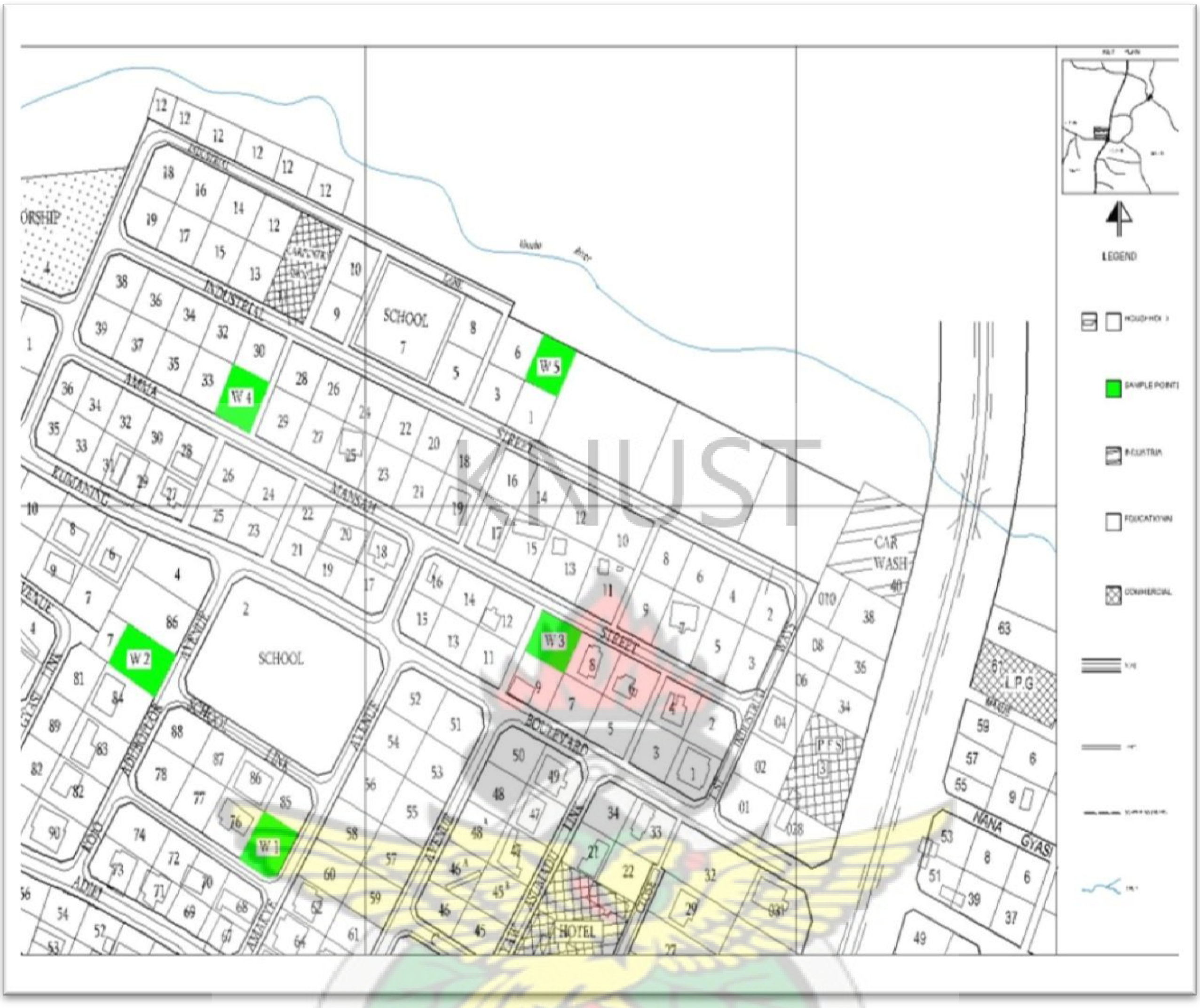

Figure 1: A map of the project site and the various sampling points.

Source: PREMP. Consult (2014)

Plate 1: Scenes from the study area showing visible signs of solid waste disposal.

Although the disposal of waste at the study area has seized for the past 10 years, there are still visible signs of solid waste especially plastic waste in the area as shown above (Plate 1). Picture A of Plate 1 shows mostly plastic waste left bare after removal of the top soil in the area, Picture B shows a heap of waste after a section of the soil has been removed to make way for construction and Picture C shows a section of the study area that is yet to be used for construction with exposed waste materials.

3.1.2 Sample collection

Two water samples were collected from each of five different hand-dug wells in various households in the project area, namely Well 1 (W1) to Well 5 (W5) along a gentle slope from top to the bottom for three months with an interval of a month making thirty (30) samples. The water samples were collected into 1 L pre-washed and screw-capped bottles that have been sterilized with water at 100 $^{\circ}$C to avoid contamination by any physical, chemical or microbial means.

All the water samples collected were stored in ice and transported to the laboratory for analysis. pH of the water samples was measured on-site with a Suntex SP-707 portable pH meter. The determinations of the other physicochemical properties of the water samples were performed on the same day of sampling. Test on samples for bacteria was conducted within 6 hours of sampling while that for anions was done within 14 days.

Plate 2: Example of a well from which water samples were taken from W1 (X4).

Plate 3: Determination of physical parameters of the water samples on site (X4).

3.1.3 Chemical analysis

A photometric method was used for the determination of Fe, NO_3^{-}, SO_4^{2-} and PO_4^{3-}, Analytical water test tablets prescribed for Palintest Photometer 5000 (Wagtech, Thatcham. Berkshire, UK) series was used. Each sample was analyzed for Fe, NO_3^{-}, SO_4^{2-} and PO_4^{3-} using procedures outlined in the Palintest Photometer Method for the examination of water.

3.1.3.1 Sulphate determination

Solutions of concentration 1µg/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 absorbance of the solution at 420nm was determined. From these data a graph of absorbance verses 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 double 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.

3.1.3.2. Phosphate determination

Ascorbic acid method (orthophosphate-Phosphorus)

Standard solutions of 1, 2, 3 and 4µg/ml were prepared. To these were added 2 ml of combined reagent. The absorbance of the solutions after 10 minutes was taken at 655nm against a blank solution. A curve of absorbance verses concentration was plotted. To 50ml of the sample was added 2ml of combined reagent. The mixture was allowed to stand for 10 minutes after which the absorbance of the sample was taken with calibrated curve. A blank analysis was performed with all the reagents without sample as a control.

3.1.3.3 Nitrate determination

Aliquots of 0.1, 0.2, 0.3 and 0.4ml 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 4 ml of colour developing reagent (Safranine O) respectively. The mixtures were diluted to 100ml mark forming 0.25µg/0.50µg/ml 0.75µg/mg 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 wavelength 543nm of absorbance. A blank analysis was performed with all the reagents without sample as a control.

3.1.3.4 Total metal determination using atomic absorption spectrophotometer (AAS)

The concentrations in mg/L of five metals were determined in all the samples namely, Cu, Zn, Pb and Fe with the Atomic Absorption Spectrophotometer. The flame used for the analysis was air-acetylene mixture. 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 to the sample treatment. The following concentrations of metal solutions were prepared to determine the baseline absorbance value at 4.0Pb: 9.4mg/L, Zn: 1.2mg/L, Cu: 3.7mg, Fe: 5.5 mg/l. The metal concentrations were determined one after the other using their respective hollow cathode lamps (HCL) and calibration curves. Air-acetylene wave flame was used for all the analysis. The respective wavelengths employed for the metal determinations were Fe at 248.7nm, Pb at 217.0nm, Zn at 213.9nm and Cu at 324.8.

3.1.3.4.1 Digestion of samples for Zn, Pb, Fe and Cu

An aliquot of 5ml of concentrated nitric acid was added to 50ml of sample of water in a 100ml beaker. This mixture was heated on a hotplate to boil until the colour of the solution became pale and clear. The solution was heated on a hot plate to boil 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 slides 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.

3.1.4. Microbial analysis

Test on samples for microorganisms was conducted within 6 hours of sampling**.** Standard methods for the determination of total coliform and fecal coliform (Brenner *et al.*, 1993; APHA, 1995) were employed

3.1.4.1. Feacal coliforms

The Most Probable Number (MPN) method was used to determine feacal coliforms in the samples. Serial dilutions of 10^{-1} to 10^{-4} were prepared by picking 1ml of the sample into 9 ml of sterile distilled water (Plate 4). One milliliter aliquots from each of the dilutions were inoculated into 5ml of MacConkey Broth and incubated at 44°C for 18-24hrs. Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24hours were identified as positive for feacal coliforms (Plate 5). Counts per 100ml were calculated from MPN tables.

Plate 4: Serial dilution of water samples for analyses.

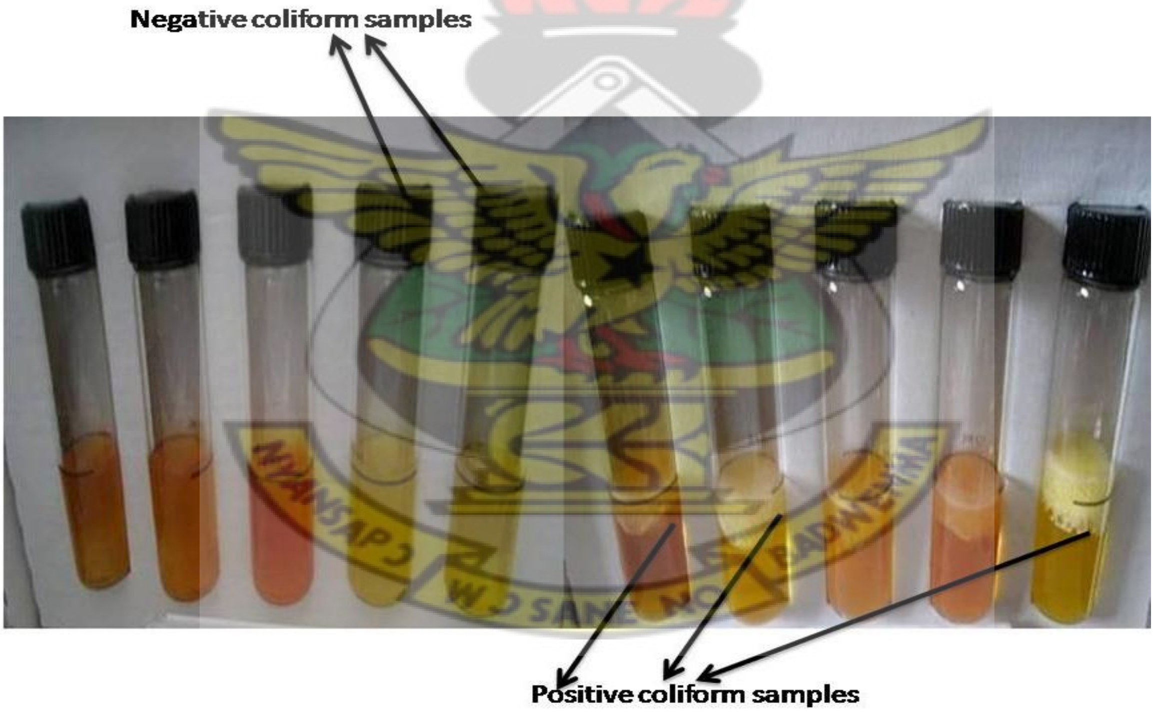

PLATE 5: Positive and negative coliform samples (X4).

3.1.4.2. *Escherichia coli (E. coli)* (thermotolerant coliforms)

From each of the positive tubes identified a drop was transferred into a 5ml test tube of trypton water and incubated at 44^{o}C for 24 hours. A drop of Kovacs' reagent was then added to the test tube of trypton water. All tubes showing a red ring colour development after agitation denoted the presence of indole and recorded as presumptive for thermotolerant coliforms (*E. coli*). Counts per 100ml were calculated from MPN tables.

3.1.4.3. *Salmonella*

Prepared 10ml of manufactured formula of Buffered Peptone Water (BPW) was in a universal bottle and serial dilution samples added to it. It is incubated at 37^{o}C for 24 hours. Then 0.1ml of the sample from the BPW was placed in 10ml of Selenite broth in universal bottle and incubated at 44^{o}C for 48hours. Swaps from the bottle were made onto Salmonella Shigella Agar (SSA) and incubated for 48 hours at 37^{o}C. Black colonies with an outer cream margin on the SSA indicate the presence of *Salmonella* .

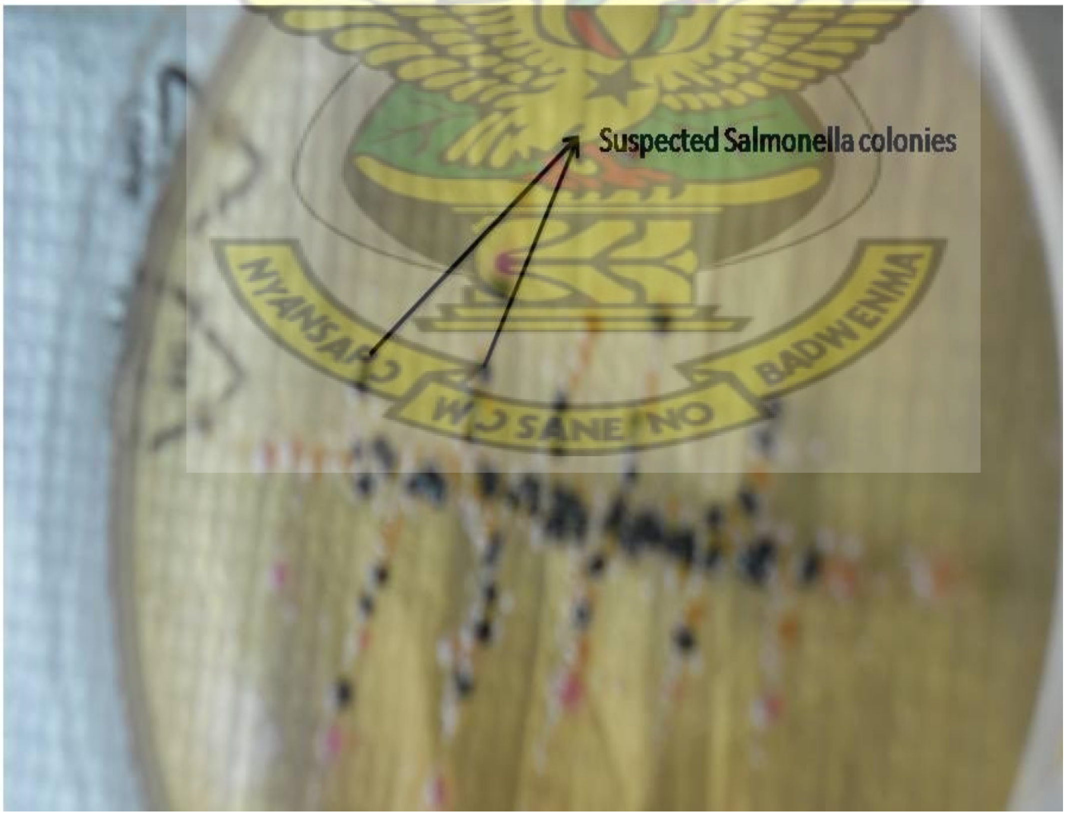

Plate 6: A petri dish showing suspected *Salmonella* colonies.

3.1.5 Statistical analysis

Tables of the mean values recorded were created using Microsoft Office Word®, the significant differences in concentration of the various parameters determined was ascertained by T-test using Graph Pad Prism Statistical Software.

CHAPTER FOUR

4.0 RESULTS

4.1 Physicochemical parameters measured for the samples

4.1.1 Dissolved Oxygen, pH and Salinity

The mean values of dissolved oxygen (DO) levels in the samples ranged from 2.17-3.54 mg/L. The pH was found to be slightly acidic although still within the recommended WHO/GSA standards, with mean values ranging from 6.36-7.01.The salinity of the water was determined with mean values ranging between 0.03 and 0.36 PSU recorded (Table 1).

The Ghana Standards Authority (GSA) has a recommended value of 1000.00 µm/cm for electrical conductivity (EC) of drinking water, the mean values however were below this recommended figure, ranging from 53-372.67 µm/cm. Total dissolved solids had mean values ranging between 26.0-377.33 mg/L (Table 1).

Table 1: Mean results of physicochemical parameters analyzed at the study area.

PARAMETERS	Mean (n=30)	Min	Max	SD	Standard
DO (mg/L)	2.78	2.17	3.54	0.56	N/A
pH	6.69	6.36	7.01	0.24	6.5-8.5
Salinity (PSU)	0.17	0.03	0.36	0.12	N/A
E. conduct (µS/cm)	347.13	53	743.33	253.65	300µS/cm
TDS (mg/L)	175.4	26	377.33	129.26	1000 mg/L

4.1.2 Nutrient levels in the water samples

The Ghana Standards Authority has a standard of 50.0 mg/L for nitrates, however mean values ranging from 0.10-0.60 were recorded. In addition to nitrates the mean values for both phosphates and sulphates were also determined with their mean values ranging from 1.23-1.49 mg/L and 1.18-1.60 mg/L respectively (Table 2).

Table 2: Mean nutrient concentration obtained in water from the study.

PARAMETERS	Mean (n=30)	Min	Max	SD	Standard
Nitrates (mg/L)	0.38	0.10	0.60	0.19	50 mg/L
Phosphates (mg/L)	1.38	1.23	1.49	0.12	1.5 mg/L
Sulphates (mg/L)	1.33	1.18	1.60	0.20	250 mg/L

4.1.3 Heavy metal contamination of water within the study area

Zinc had mean values ranging from 0.08-0.69 mg/L, iron ranging from 0.29-1.46 mg/L and copper from 0.05-0.19 mg/L. Unlike the mean values for the above mentioned heavy metals the mean value of Lead was far above the GSA/WHO recommended levels (0.01 mg/L), the values ranged from 0.17-0.31 mg/L (Table 3).

Table 3: Mean heavy metal concentration in the water samples analyzed.

PARAMETERS	Mean (n=30)	Min-	Max	SD	Standard
Zinc (mg/L)	0.69	0.08	0.69	0.26	3 mg/L
Lead (mg/L)	0.23	0.17	0.31	0.05	0.01 mg/L
Iron (mg/L)	0.70	0.29	1.46	0.48	10-50 mg/L
Copper (mg/L)	0.11	0.05	0.19	0.06	2mg/L

4.1.4 Microbial quality of the water sampled

The microbial quality of the water was also determined with mean values of feacal coliforms ranging between 3.29×10^4 and 3.81×10^4cfu/100ml, clearly above the recommended GSA standard (0 cfu/100ml).*E. coli* was also measured, giving mean value ranging between 0.94×10^2 cfu/100mland 2.03×10^2cfu/100ml. However *Salmonella* was found to be absent (Table 4).

Table 4: Mean microbial contamination levels in the water samples.

PARAMETERS	Mean (n=30)	Min	Max	SD	Standard
Feacal coliforms ($\times10^4$ cfu/100 ml)	3.48	3.29	3.81	0.23	0 cfu/100mL
E. coli ($\times10^2$ cfu/100 ml)	3.48	0.94	2.03	0.23	0 cfu/100mL

CHAPTER FIVE

5.0 DISCUSSION OF RESULTS

5.1 Physical quality of the water samples

The physical parameters of the water sampled were within the WHO and GSA standards, with the exception of pH from W2, in which case the recorded value was far below the standard, this could be attributed to the bedrock and soil composition through which the water moves, both in its bed and as groundwater. pH values below 6.5 makes the water too acidic for human consumption, water with such low values could cause serious health complications due to acidosis. The pH of a water body influences the concentration of many metals by altering their availability and toxicity. Metals such as zinc (Zn) and cadmium (Cd) are most likely to have increased detrimental environmental effects as a result of lowered pH (Lawson, 2011).

The total dissolved solids (TDS), an index of conductivity, has a direct relationship to salinity and high total dissolved solids limits the suitability of water for potable use (Davis and DeWiest, 1966) as was evident in this study. The trend of values recorded for these parameters were similar throughout the study thereby confirming their interlinked nature. From this current survey values of these parameters were all within the allowable standards for drinking water as set by the WHO and GSA.

5.2 Heavy metal and nutrient contamination of the water

Trace metals are essential components of human nutritional requirements, but these are only needed in minute quantities as high levels have serious health effects. As mentioned earlier high levels of nitrate leads to various health issues. The levels of these trace elements in the water sampled for this study was not high. These metals are often present in varying concentrations depending on prevailing factors (pH, temperature, water hardness and standing time of the water). Manganese, iron and lead were monitored because they account for most consumer complaints (WHO 2006; 2003).

Refuse dumps serve as grounds for the disposal of various kinds of waste, from degradable to non-degradable including various kinds of metals. The project site having served as a refuse dump for the Kumasi Metropolis until 10 ago years when dumping was stopped, had high levels of lead exceeding the allowable limit set by the GSA (0.01 mg/L). Lead could get access to drinking water from plumbing works, brass and many other alloys that contain it. The leaching of lead into water bodies occurs during high temperatures, therefore with the constant high temperatures in Kumasi, the leaching of this metal into the underground waterbed is a high possibility. Then also since the study area was once used as a dumping site for municipal waste, there could have been materials that contained Lead thereby through leaching and other processes contaminated the underground water. High levels of Lead have many adverse effects on the health of human consumers. Lead has a cumulative effect on infants (Children up to the age of six years), with the foetus and pregnant women being the most susceptible to adverse health effects. Acute intoxication with lead results in dullness, restlessness, irritability, poor attention span, headache, muscle tremor and many more other signs. These signs mostly occur at blood lead levels of 100-120µg/dl in adults and 80-100 µg/dl in children (USEPA, 1986). Signs of chronic lead toxicity include tiredness, sleeplessness, irritability, headache, joint pains and gastrointestinal symptoms, in adults these appear at blood levels of 50-80 µg/dl (WHO, 2011). Renal diseases have also been associated with Lead poisoning and then also when blood lead reaches 37µg/dl it can result in increased hypertension (WHO, 2011). Aneamia could also result due to high blood lead contents, because this element interferes with the activity of the major enzymes involved in synthesis of haem (USEPA,1986), This occurs at blood lead levels in excess of 40µg/dl in children and 50 µg/dl in adults.

5.3 Microbial Quality of the water

Although WHO guidelines recommend the absence of microbial indicators in any 100 ml of drinking water this study recorded high numbers of faecal coliforms (10^4) and *E. coli* (10^2). Treated pipe water received in consumer homes within the Kumasi metropolis sometimes contain coliform bacteria varying from 30 - 78 MPN $100ml^{-1}$ total coliforms and 0 -18 MPN $100ml^{-1}$feacal coliforms (Quist,1999). In a similar work on wells within urban Kumasi, Quist (1999) recorded lower faecal coliform counts of 1.45×10^5, 2.5×10^5 and 4.5×10^2. High microbial counts for potable water have been found in several earlier studies in the tropics. Thielman and Geurrant (1996), Feachem (1980), Cairncross and Cliff (1987),Obiri-Danso *et al.,* (2008) and Cairncross (1987) have all reported faecal coliform counts greater than $10^4$from rivers, ponds. It has been shown that land disposal of sewage sludge, illegal dumping of septic tank pumpage, improper toxic waste disposal and runoff from agricultural operations all contribute to groundwater contamination with microorganisms, therefore water from a location that was once the landfill site for the city of Kumasi is expected to have feacal and *E. coli* of such magnitude, therefore the contamination of the underground water from the area with bacterial colonies could be attributed to that in addition to other factors, such as, wells without adequate cover from external contamination, contaminated receptacles used in fetching the water etc.

Similar results were obtained by Obiri-Danso *et al.*, (2008) from water samples picked from wells close to refuse dumps in various suburbs of the Kumasi Metropolis. It was observed in some cases that filters were used to filter the water before being used, this was seen in three out of the five sampling points, water from these points although did not have any significant lower levels of nutrients or metals, but rather had the lowest levels of both feacal and *E. coli* counts.

These sites in addition to the filters in use also had pipes through which the water is drawn and therefore results in less contamination. In the absence of these pipe systems and filters, the well water was drawn normally using various receptacles (plastic or aluminium buckets) with varying degrees of hygiene. These receptacles were also used for other purposes including bathing and laundering. Similarly all users had to use one rope for drawing water which was often left in water that had been spilt around the wellhead. It is recommended that wells should be raised well above the surrounding ground level to divert run-off water but this was not the case with some of the wells included in this study. The construction and depth of the wells could further explain contamination levels. Ideally, wells should be constructed with concrete ring pipes but due to financial constraints only the upper 2 m were cemented thus allowing easy seepage. Kumasi is a low lying area and one need not dig deep to hit the water table. Hence filtration, adsorption and trapping of bacteria by fine sandy materials, clays and organic matter is not effective and therefore a serious contributing factor to the levels of bacteria recorded.

CHAPTER SIX

6.0 CONCLUSSION AND RECOMMENDATIONS

6.1 CONCLUSSION

Water is an indispensable resource necessary for the sustenance of life. Due to rapid urbanization, water supply in developing countries (including Ghana) is inadequate, resulting in the sourcing of water from various avenues. One of such avenues is the reliance on hand dug wells or boreholes due to the unreliability of water supply form the Ghana Urban Water Company. The physicochemical quality of the water sampled from Ahenema Kokoben as determined in this study can be said to be of acceptable limit for human consumption, except for lead which was above the WHO Standard set for drinking water. The turbidity, TDS and conductivity values observed during the analysis were all within the WHO permissible limit. However the microbiological quality of the water was not good enough as *E. coli* was detected as well as feacal coliforms, indicating a possible feacal contamination.

Again, a higher Lead content was recorded, Lead in drinking water has various adverse health effects, such as, in babies and children, exposure to lead in drinking water above the action level can result in delays in physical and mental development, along with slight deficits in attention span and learning abilities. In adults, it can cause increases in blood pressure. Adults who drink this water over many years could develop kidney problems or high blood pressure. From the above findings, it can be concluded that water samples from this study area is found to be unwholesome for drinking according to both the WHO and GSA standards for drinking water, due to the presence of feacal coliforms and *E. coli* and then also high concentrations of lead.

6.2 RECOMMENDATIONS

Based on the outcome of the study the following is recommended;

1. The Ministry of Water Resource Works and Housing should review its policy on private water provision especially with respect to borehole and hand dug well drilling. The Ministry should provide community-based water supply system for each community whereby one or more high yield boreholes are drilled and pumped up into a tank and distributed via pipe lines to the whole community so that different boreholes are not drilled, thereby reducing the possibility of contaminating the groundwater at various sources.
2. The Ministry should also demand that Real Estate Developers, in consultation with the Water Resources Commission, use the Global Positioning and Geographical Information Systems to forecast good groundwater sources by testing for the quality and spatially locating the position of the ground water source, with the view to drill a high-yield borehole of good water quality for their estates, as the estate developers develop the estates far ahead of social amenities, potable water inclusive.
3. It is recommended that the district Assembly carry out water quality analysis on all the boreholes in the area at least once every two years. This will ensure that incidence of contamination are noticed earlier for remedial action to be taken.
4. The inhabitants should be educated on the need to keep their surroundings clean most especially around the boreholes.
5. The communities should be educated on the dangers associated with sighting boreholes down slope, at dumping sites and public places of convenience uphill.
6. It would be highly recommended that water from the project area is not used as drinking water due to the high levels of Lead and faecal coliform indications. It may however be used for all other domestic purposes except drinking and cooking.
7. Where it becomes necessary to drink, water from the project site should be boiled before drinking as faecal coliform indications were high.

REFERENCES

Abid, M.A. and Jamil, A. (2005). The Assessment of Drinking Water Quality and Availability in NWFP,RWSSP, Peshawar.

American Public Health Association. (APHA) (1995). Standard methods for the examination of water and wastewater. 19th ed. American Public Health Association; Washington, D.C.

Anawara, H.M.; Akaib J.; Mostofac, K.M.G.; Safiullahd, S.and Tareqd, S.M.(2002). Arsenic poisoning in ground water health risk and geochemical sources in Bangladesh. *Environ Int.*;27:597–604.

Anderson, K.L., Whitlock, J.E. and Harwood, V.J. (2005). Persistence and differential survival of fecal indicator bacteria in subtropical waters and sediments. *Appl Environ Microbiol* 71, 3041–3048

Angelova, M., Asenova, S., Nedkova, V. and Koleva-Kolarova, R. (2011). Copper in the human organism. *Trakia Journal of Sciences*, Vol. 9, No 1, pp 88-98,

Angulo, F.J., Maybeck, M. and Stanley, D.W. (1997). A community waterborne outbreak of Salmononellosis and the effectiveness of a boil water order. *American Journal of Public Health 87 : 580-58*

Ashbolt, N. J., Grabow, W. O. K. and Snozzi, M. (2001). In "Water Quality: Guidelines, Standards and Health. Risk assessment and management for water-related infectious disease, Chapter 13" (L. Fewtrell and J. Bartram, eds), pp. 289-315. *IWA Publishing, London*

Berg, G. (1978). The Indicator System. In Indicators of Viruses in Water and Food (ed.G.Berg), pp. 1-13, *Ann Arbor Science Publishers, Ann Arbor, MI.*

Brenner, K.P., Rankin, C.C., Roybal, Y.R., Stelma, G.N., Jr, Scarpino, P.V. and Dufour, A.P.,**(1993)** New medium for the simultaneous detection of total coliform and *Escherichia coli* in water. *Appl. Environ. Microbiol. 59:3534-3544. EPA/600/J-99/225*

Bruvold, W. H. and Ongerth, H. J. (1996). Taste quality of mineralized water. *Journal of the American Water Works Association.*61;170.

Cairncross, S.and Cliff, J.L. (1987). Water use and health in Mireda, Mozambique, *Trans. Royal Soc. Trop.Med.Hyg*. 81:51-54

Clark, M.A. and Barret, E.L., (June 1987). The pHs gene and Hydrogen Sulphide Production of *Salmonella typhimurium*. *Journal of Bacteriology 169 (6) 2391-2397*

Davis, S. and De Weist, R. (1966). Hydrogeology.*John Wiley &Sons, Inc., New York, p463*

Diersing, N. (2009). "Water Quality: Frequently Asked Questions. Florida Brooks National Marine Sanctuary, Key West, FL

Dissanayake, C.B. (1991). The Fluoride Problem in the Ground Water of Sri Lanka, - Environmental Management and Health Intl. *Journal of Environmental Studies*: vol 19: 195-203

Doyle, M.P., and Erickson, M. C.(2006). Closing the door on feacal coliform assay. *Microbe1*:162-163. ISSN 1558- 746

Eckburb, P.B., Bik, E.M., Bernstein, C.N., Purdom, E. and Dethlefsen, L. (2005). Diversity of the human intestinal microbial flora, *Science* 308: 1635-1638

Edwards, D.D. (1993). Troubled water in Milwaukee. *ASM News* 59, 342–345

Elinder, C.G,(1986). Zinc. In: Friberg, L., Nordberg, G.F., Vouk, V.B. eds. Handbook on the toxicology of metals, 2nd ed. Amsterdam, Elsevier Science Publishers, 664 – 679

Faechem, R.G., (1980). Bacterial standards for drinking water quality in developing countries. *Lancet* 2:255-256.

Fei- Baffoe, B. (2008). Pollution Control, IDL Course Material for BIOL 505, MSc Environmental Science-KNUST, Kumasi. Pp 50, KNUST Press (2008).

Fewtrell, L., Kaufmann, R., Prüss-Üstün, A. (2003). *Lead: Assessing the environmental burden of disease at national and local levels*. Geneva, World Health Organization (Environmental Burden of Disease Series, No. 2;

Fuare, G. (1998). Principles and applications of geochemistry. 2nd Ed. Upper Saddle River (NJ) Prentice Hall, pp600

Ghana Standards Board (1998). Water quality requirements for drinking water, part 1: GS 175

Government of Ghana, Ministry of Water Resources, Works and Housing: National Water Policy Document (2007)

Grabow, W.O.K. (1996). Waterborne Diseases; Update on Water Quality Assessment and Control. *Water SA*: 22: 193-202

Greenhalgh Alison (2001). Healthy living water, BBC Health. http/www.co.uk/healthy living. (Accessed November12, 2013)

Gupta, D.P., and Saharan, J.P. (2009). Physicochemical Analysis of Groundwater of selected Area of Kaithal City (Haryana) India, *Researcher*, 1(2), pp1-5

Harvey, C. F., Ashfaque K. N., Yu, W., Badruzzaman, A.B.M., Ashraf, M., Ali, P., Oates, M., Michael, H. A., Neumann, R. B., Beckie, R., Islam S. and Ahmed M. F. (2006). Groundwater Dynamics and Arsenic Contamination in Bangladesh, *Chemical Geology*, 228, 112-136,

http//environment.about.com/environmental events/waterdayqa.htm/ Date accessed: 12/12/2013

http//www. water research.net /watershed/phosphates.htm. Date accessed: 9/12/13

IARC (2006). Summaries & evaluations: Inorganic and organic lead compounds. Lyon, International Agency for Research on Cancer (IARC Monographs for the Evaluation of Carcinogenic Risks to Humans, Vol. 87; http://www.inchem.org/documents/iarc/vol87/volume87.pdf).

Ifabiyi, I.P. (2008). Self-Purification of a Freshwater Stream in Ile- Ife; Lessons for Water Management*: J. Hum Ecology* 24(2) 131- 137

International Development Law Organization (IDLO) (2006). Water Tenure Reform and Public Access to Water as a Basic Need, International Development Law Organization Voice of Development Jurists Series.

Kishore, M. and Hanumantharao, Y. (2010). A survey on fluoride concentration in drinking water of tipparthy revenue sub-division, Nalgonda District, andhrapradesh, India and batch mode defluoridation with renewable resources. *Rasayan J. Chem* Vol. 3 No. 2:341-346

Kortatsi, B. K. (2006). Hydrochemical Characterization of groundwater in the Accra Plains of Ghana. *Environmental Geology Journal* vol 50 pp 299 – 311

Kot, B., Baranowski, R. and Rybak, A. (2000). Analysis of mine waters using X-ray fluorescence spectrometry. *Polish J Environ Stud.*;9:429.

Krishnan, J. R. (2008). Investigation on Hydrobiology and Water Quality Parameters Of Periyar Lake, Thekkady, Kerala (PhD Thesis), Mahatma Ghandi University, Kerala, India

Kwakye-Nuako, G., Borketey, P.B., Mensah-Attipoe, I., Asmah, R.H. and Ayeh-Kumi, P.F. (2007). Sachet Drinking Water in Accra: The Potential Threats of Transmission of Enteric Pathogenic Protozoan Organisms. *Ghana Med J.*;41(2):62–7.]

Lawson, E.O. (2011). Physico-chemical parameters and heavy metal contents of water from the mangrove swamp of Lagos Lagon, Lagos, Nigeria. *Biological Resaerch 5(1):08-21*

Lewis, W.J., Foster, S.S.D. and Drasar, B.S. (1982).The Risk of Groundwater Pollution by On-site Sanitation in Developing Countries. *IRCWD Report 01/82, IRCWD, Duebendorf, pp 79*

Li, Y. (2001). Effect of long-term exposure to fluoride in drinking water on risks of bone fractures. *Journal of Bone and Mineral Research*, 16(5):932–939.

MacKinnon, A.U., Taylor, S.H. (1980). Relationship Between Sudden Coronary Deaths and Drinking Water Hardness in Five Yorkshire Cities and Towns. *International Journal of Epidemiology* (3):247-248

Marie, A., Khayat, S. and Dajani, M. (2012).Water quality legislation in Palestine over the past century. *Environmental Sciences Europe* 24:15

McGowan, W. (2000). Water Processing: residential, commercial, light industrial, 3rd ed. Lisle, IL, Water Processing Association.

Ministry Of Food and Agriculture (2013).Agricultural activity in the Ashanti Region.www. gov.gh/MOFA. Accessed on 23rd November, 2013.

National Groundwater Association (NGA) (Accessed Feb 11 2013). 601 Dempsey Road, Westerville, Ohio. 614-898-7791. http://www.h2O-ngwa.org/pubaff/bacq_a.html.

National Research Council (1997). Drinking Water and Health, Washington D.C National Academy of Sciences

Neri, L. C. and Johansen, H. L. (1978).Water hardness and Cadiovascular mortality. *Annals of the New York Academy of Sciences*, 304: 203- 221

Nriagu, J.O. (1980). Zinc in the environment. Part I, Ecological Cycling. New York, NY, John Wiley.

Obiri-Danso, K., Adjei, B., Stanley, K.N. and Jones, K. (2008). Microbiological quality and metal levels in wells and boreholes water in some peri-urban communities in Kumasi, Ghana. *African Journal of Environmental Science and Technology*, vol. 3(1), pp059-066

Obiri-Danso, K., Okore-Hanson, A. and Jones, K. (2003). The microbiological quality of drinking water sold on the streets in Kumasi, Ghana. *Letters in Applied Biology*.37; 334-339.

Oluyemi, E.A., Adekunle, A.S., Adenuga, A. A. and Makinde, W.O. (2010).Physico-Chemical Properties and Heavy Metal content of water sources in Ife North Local Government Area of Osun State, Nigeria : *African Journal of Environmental Science and Technology* vol 4 (10) Pp 691-69

Osei- Akoto, D. (2009). Environmental Chemistry, IDL Course Material for Chem 514, MSc Environmental Science – KNUST, Kumasi,Pp 59, KNUST Press (2009)

Putz, J. (2003). Chemical analysis of drinking water for India-Canada Environment *www.docstoc.com/docs/.../Chemical-analysis-of-drinking-water*.(Accessed January 23rd 2014).

Quinn, M.J. and Sherlock, J.C. (1990). The correspondence between U.K. 'action levels' for lead in blood and in water. *Food additives and contaminants*, 7:387-424.

Quist, K.A. (1999). Feacal indicators in drinking water in the urban area of Kumasi. Msc. Dissertation, Biological Sciences, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Singhl, S. and Mosley, L.M. (2003). Trace metal levels in drinking water on VitiLevu, Fiji Islands. *S Pac J Nat Sci*.;21:31–4.

Snyder, J. D. and Merson, M. H. (1982). The Magnitude of the Global Problem of Acute Diarrheal Disease: A Review of Active Surveillance Data. *Bulletin of the World Health Organization. 1982;60:605–13*

Sorrels, K. M, Speck, M. L. and Warren, J. A. (1970).Pathogenicity of *Salmonella gallinarum* After Metabolic Injury by Freezing.*Applied and Environmental Microbiology* 19(1) 39-4

Stallard, R.F and Edmond, J.M. (1983).Geochemistry of Amazon River-The influence of the geology and weathering environment on the dissolved load; *J. Geophys. Res*. 88:9671-9688

Thielman, N. and Geurrant, R.L. (1996). From Rwanda to Wisconsin: The global relevance of diarrhoeal diseases. *J. Med. Microbiol.* 44: 155-156.

Umar, R., and Absar, A. (2003).Chemical characteristics of groundwater in parts of the Gambhir river basin, Bharatpur District, Rajasthan, India. *Environmental Geology*, 44:535–544

Umar, R., Muqtada, M., Khan, A., and Absar, A. (2006).Groundwater hydrochemistry of a sugarcane cultivation belt in parts of Muzaffarnagar district, Uttar Pradesh, India. *Environmental Geology*, 49: 999–1008

United Nations Development Programme (UNDP) (2002). Statement by UNDP Administrator Mr.MarkMalloch Brown.

United Nations Environmental Program (UNEP) Report (2009). Water, Sanitation and the UN: 14: 02.

US Environmental Protection Agency (1986). *Air quality criteria for lead.* Research Triangle Park, NC,(Report EPA-600/8-83/028F).

US Environmental Protection Agency (1997).Sources of ground water contamination. Agricultural and Biological Engineering Department. Purdue University Indiana.

Water Aid Annual Report(2008). Annual Report 2008/09

WHO/UNICEF (2004). Joint Monitoring Programme for Water Supply and Sanitation. SANITATION and DrINkINg-wATer Progress on 2004 UPDATE

WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (2010). Progress on Sanitation and Drinking-water: Update.*Publications of the World Health Organization can be obtained from WHO Press, World Health Organization, 20 Avenue Appia, 1211 Geneva 27, Switzerland*

Wolfhard, S., Reinhard, B. (1998). The Heterogeneity of Runoff and its Significance for Water Quality Problems. *Hydrological Sciences Journal* ***43:*** *103-113*

World Bank (1997). Water and Development: An Evaluation of World Bank Support. The World Bank Group.

World Health Organisation (1984).Guidelines for Drinking Water Quality. (1). Recommendations, World Health Organisation Standards. Geneva, Switzerland.

World Health Organization (1996). Guidelines for drinking water quality. 2. World Health Organization;.p.231.

World Health Organization (1993).Recommendations.Second Edition.Vol. 1. Geneva: World Health Organisation; Guidelines for drinking water quality. ISBN 94-4-154503.

World Health Organization (2002). Managing Water in the Home: Accelerated Health Gains from Improved Water Supply. Geneva: World Health Organisation, Document No. WHO/SDE/WDE/WSH/02. Available: http://www.who.int/phe.

World Health Organization (2003). Iron in drinking water. Background document for preparation of WHO Guidelines for drinking water quality. Geneva, World Health organization. (WHO/SDE/WSH/03.04/8).

World Health Organization (2003).World Health Report.Shaping our future. World Health Organisation. ISBN 9241562439 (http://www.who.int/whr/en/). Date accessed: 20th May, 2013

World Health Organization (2006). Guidelines for drinking water quality.Third edition, WHO Press, Geneva, Switzerland.Pp. 398.

World Health Organization (2008). Guidelines for Drinking Water Quality, 3rd ed. Vol 1. Incorporating the first and Second Addenda, WHO, Geneva (2008): ISBN 978 92 4 154761

World Health Organization (2010).Guidelines for drinking-water quality. http://www.who.int/en/. Accessed on 23rd November, 2013.

World Health Organization (2011). Lead in drinking water: Background document for development of WHO Guidelines for drinking water quality WHO/SDE/WSH/03.04/09/Rev/1

www. Mofa.gov.gh/atwimakwanwoma.Date accessed 13th March, 2014.

Zuane, J. D. (1990). Drinking Water Quality: Standards and Control, Van Nostrand Reinhold, New York

APPENDICES

APPENDIX I

Table 4.1.2. Values of nutrient levels within the study area.

SAMPLE ID	NITRATES	PHOSPHATES	SULPHATES
WHO STANDARD	50.0 mg/L		250.00 mg/L
W1	0.490	1.42(+/-0.230)	1.17(+/-0.167)
W2	0.590	1.45(+/-0.080)	1.21(+/-0.144)
W3	0.090	1.44(+/-0.135)	1.20(+/-0.200)
W4	0.340	1.27(+/-0.099)	1.59(+/-0.150)
W5	0.490	1.35(+/-0.084)	1.74(+/-0.094)

Table 4.1.3 Mean values of heavy metals in the study area.

SAMPLE ID	Zinc	Lead	Iron	Copper
WHO STANDARD	**3.00 mg/L**	**0.010 mg/L**	**0.3–3 mg/L**	**2.00 mg/L**
W1	0.200	0.173	0.584	0.194
W2	0.108	0.192	0.823	0.053
W3	0.075	0.208	0.287	0.078
W4	0.693	0.239	0.325	0.167
W5	0.137	0.313	1.460	0.066

Table 4.1.4: Mean values of physical parameters

SAMPLE ID	DO	pH	EC	TDS	Salinity
WHO STANDARD		6.50-8.50	1500.00µm/cm	1000.00 mg/L	
W1	3.54(+/-0.019)	7.01(+/-0.015)	53.0(+/-1.15)	26.0(+/-0.58)	0.03(+/-0.0058)
W2	2.61(+/-0.012)	6.36(+/-0.021)	333.67(+/-0.882)	166.0(+/-0.577)	0.16(+/-0.0088)
W3	2.42(+/-0.012)	6.72(+/-0.015)	233.0(+/-1.154)	117.0(+/-0.577)	0.11(+/-0.015)
W4	3.18(+/-0.046)	6.60(+/-0.058)	743.33(+/-25.20)	377.33(+/-1.855)	0.36(+/-0.032)
W5	2.17(+/-0.015)	6.76(+/-0.012)	372.67(+/-2.848)	190.67(+/-1.202)	0.18(+/-0.009)

Table 4.1.5: Mean microbial loads of the study area

SAMPLE ID	FEACAL COLIFORMS	*E. coli*	*Salmonella*
WHO STANDARD	NIL	**NIL**	**NIL**
W1	3.63×10^4	2.02×10^2	ND
W2	3.29×10^4	1.43×10^2	ND
W3	3.32×10^4	1.00×10^2	ND
W4	3.34×10^4	0.94×10^2	ND
W5	3.81×10^4	2.03×10^2	ND

APPENDIX II: WHO Guideline values for the Analyzed Parameters in drinking water.

Parameter	WHO Guideline value
Colour	Below 15 colour units
Total hardness	200mg/L
pH	6.5 – 8.5
Conductivity	300µS/cm
Nitrates	50mg/l
Nitrite	0.2mg/l
Sulphate	-
Fluoride	500mg/l
Phosphate	1.5mg/l
Copper	-
Lead	0.01mg/l
Iron	10 – 50mg/l
Zinc	3mg/l
E. coli	NIL
Faecal coliforms	NIL
Salmonella	NIL