KWAME NKRUMAH UNIVERSITY OF SCIENCE AND

TECHNOLOGY

COLLEGE OF SCIENCE

WELL WATER QUALITY OF THE OTI COMMUNITY IN THE KUMASI METROPOLIS OF GHANA

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In

ENVIRONMENTAL SCIENCE

BY

SETH KWADWO OSEI

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DECLARATION

I hereby declare that this submission is my own work towards the master of Science (MSc.) degree, and that, to the best of my knowledge, it contains no material previously published by another person or material which has been accepted for the award of any other degree by the university, except where due acknowledgement has been made in the text.

Seth Kwadwo Osei ……. ………………. ………………………..

(Student) Signature Date

Certified by:

Mr. Eric A. Agyapong ……………………. ………………………

(Supervisor) Signature Date

Dr. I.K Tetteh ……………………… ……………………….

(Head of Department) Signature Date

DEDICATION

The work is dedicated to my children, Nana Serwah and Osei Amoako

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ABSTRACT

The quality of water from selected hand dug wells within the Oti community, a peri urban community in the Kumasi metropolis has been studied. Monthly water samples were collected from 24 hand dug wells, and analyzed for physico-chemical and bacteriological parameters using standard methods. Results of the study show that levels of TDS, electrical conductivity, salinity, chloride, phosphate and nitrate were within the recommended World Health Organization and Ghana Water Company recommended guideline limits for drinking water. However, the water samples were mostly acidic, recording pH of 5.41-6.54. The total hardness of the water ranged from 36.13-121 mg/l, making most of them mostly soft to moderately hard. Iron concentrations were relatively high compared with WHO and GWC standards. Total coliforms, faecal coliforms and *E. coli* counts per 100 ml of sample ranged: 3.4×10^4-2.35×10^6, 2.3×10^4-9.20×10^5 and 3×10^4-4×10^4, respectively. The presence of these microbiological indicators in the samples indicates contamination from human and animal sources, and may pose a health risk to consumers of water from the wells.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Water is one of the essential resources for the survival of all living organisms. It is an indispensable resource for life and subsistence. There is no doubt that the role water plays in the economic and social well-being of all mankind cannot be ignored. Water resources are the backbone to important and key economic and social activities such as agriculture, industry, hydropower generation, transportation, recreation, sanitation, water supply, etc. The availability and access to fresh water in most developing countries like Ghana, influences the trend of economic growth and social development (Odada and Olago, 2006). Apart from the economic value, freshwater plays a pivotal role in addressing the issues of health, poverty and hunger.

In Ghana, surface water covers five percent of the total land area. This is available for industry, agriculture and community water supply (EPA, 2004). Agriculture and industry are the largest and least users of water, respectively. However, the increase in population, urbanization, agriculture and their related pollution problems have resulted in the decline of the available fresh water especially for domestic purposes. Safe and potable water is essential for reducing the incident of water borne diseases such as Cholera, typhoid, hepatitis, diarrhea, etc. which causes considerable deaths in developing countries (WHO, 2008). Access to clean water and sanitation considerably reduces water related diseases which kills thousands of children every day (UN, 2006). According to the World health organization (WHO), 1.1 billion people lacked access to water supply in 2002 and 2.3 billion got ill through the consumption of unhygienic water (WHO, 2004).

A primary concern of people living in developing countries is that of obtaining clean drinking water. In Africa, most people have resulted to alternative water supplies such as rain harvesting, surface water and groundwater to augment the short fall in traditional water supply systems. The situation is not different in most parts of Ghana. Groundwater has therefore become the preferred choice of potable water for rural and urban communities in the country. Majority of the rural and peri-urban communities in Ghana rely on untreated groundwater sources for domestic purposes. The development of groundwater resources for potable use has increased substantially over the past decade. In the United States of America, 90-95 percent of potable water supply for rural and suburban communities is obtained from groundwater (Howell *et al.*, 1995). In Ghana, groundwater constitutes about 62-71 percent of water supply for rural and peri-urban dwellers (GEM/Water project, 1997). This is mainly used for domestic purposes.

The acceptance and increased popularity of groundwater as an alternative choice of potable water resource is due to certain features and characteristics that have made it attractive as a good source of water supply. It can be tapped at shallow depths near the water demand centres. It is protected naturally from evaporation offering water supply security in arid areas. Groundwater has excellent microbiological and chemical quality which requires minimal treatment due to adequate aquifer protection (Quist *et al.*, 1998). It is less expensive and flexible to develop (Dapaa-Siakwan and Gyau-Boakye, 2000).

The government of Ghana in collaboration with some non-governmental organizations (NGOs) has constructed hand dug wells and boreholes to augment the water supply in the country. This is aimed at providing cheap, safe and potable water for most scattered urban and rural communities.

The water supply system in Kumasi currently has 1,005 km of pipeline supplying potable water for both domestic and industrial purposes (Kuma *et al.*, 2010). These pipelines carry treated water from two main sources, the Barekese and Owabi head works. Blokhuis *et al.* (2005), reported that although water production in the metropolis has increased from 21 to 25 million gallons per day between 2005 and 2010, the average per capita daily consumption has been declining. Kuma *et al*. (2010), estimated that the daily per capita water consumption in 1999 was 66 litres per day which should have risen to 94 litres per day.

However, the average water production from these two head works only covers 51 percent of the population in the metropolis. This is largely due to the ever- increasing population growth which has outstripped supply. Other challenges include leakages from pipe lines, irregular power supply, and reduction of the intake volumes at both the Owabi and Barekese head works (Kuma *et al.*, 2010).

The inability of the water supply systems in the Kumasi metropolis to meet the growing demands have resulted in the search for alternative sources of water supply. In communities which do not have access to the current water supply facilities, groundwater has become the preferred choice. Mechanized boreholes and hand dug wells have been constructed to provide the needed water for domestic purposes.

In Ghana, groundwater resources are under increasing pressure in response to threats of rapid population growth, coupled with the establishment of human settlements lacking proper water supply and sanitation services (Anim *et al.*, 2011).

1.2 Statement of the Problem

The Oti community is one of the immediate communities around the Kumasi waste management treatment facility at Dompoase. The waste treatment facility is the principal waste disposal and treatment site for both solid and liquid waste generated from the metropolis. Although it is an engineered landfill site, the threat of groundwater pollution cannot be ignored. When properly constructed, landfill leachate produced can be controlled and prevented from polluting the groundwater. However, there have been instances where contamination and pollution of groundwater have been reported around landfill sites in some parts of the world.

Srinivasan (1977), reported groundwater contamination by leachate from refuse dumps in Ontario, Canada. Murry *et al.* (1981), have observed severe contamination of groundwater near sanitary landfill operations in Missouri, USA. In another study in India by Gopal *et al.* (1991), high levels of water hardness in groundwater near dump sites were reported in the city of Kupal. Nicholson *et al.* (1983), reported high levels of sulphate and iron above recommended limits for drinking water in groundwater near a landfill site in Ontario, Canada.

Notwithstanding these concerns, the immediate communities within the vicinity of the Dompoase landfill site depend on groundwater for their entire domestic water supplies. This has become imperative due to the absence of treated water supply facilities within these communities. Hand dug wells and boreholes have, thus, become the main methods of abstraction within these communities. These non-treated water sources are being used for drinking water and other domestic purposes. This study therefore, aimed at assessing the quality of groundwater being used by this community.

1.3 Justification

The quality of groundwater is constantly changing in response to daily, seasonal and climatic factors. The quality of water has far reaching consequences in terms of its effects on man and biota. Water quality data is also vital for the implementation of responsible water quality regulations for characterizing and remediating contamination and for the protection of the health of humans and the ecosystems. Regular monitoring of groundwater resources thus plays an essential role in sustainable management of water resources. Therefore, it is important for this study to be undertaken to ascertain the water quality parameters which the inhabitants depend on for their survival.

1.4 Objectives

The main objective of the study was to assess the water quality of hand dug wells in the Oti community.

The specific objectives were to determine:

1. The levels of some physico-chemical parameters such as pH, total dissolved solids, conductivity, salinity, total hardness, chloride, phosphate, iron, calcium and nitrates in some selected hand dug wells in the community.

2. Total coliform, feacal coliform and *E.coli* counts from selected hand dug wells.

3. The possible sources of pollution influencing the microbial and physico-chemical quality of groundwater in the community.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Groundwater has become the most preferred source of water for domestic purposes due to inadequate and intermittent water supply from traditional systems. Lack of clean drinking water and sanitation services leads to water related diseases. Snyder and Merson (1982), estimated that between five to ten million deaths in children occur globally due to water related diseases. Large portions of the populace in developing countries die annually as a result of water borne diseases such as cholera, typhoid, hepatitis, diarrhea, etc. (WHO, 2008).

In the Kumasi metropolis, Ghana Water Company Limited (GWCL) is mandated to supply and distribute potable water for the city and urban dwellers. The company is unable to supply adequate quantities to meet the requirements within the metropolis. Feachem *et al.* (1978), observed that in most developing countries several factors may cause these difficulties. This is largely due to the ever increasing population, lack of funds for capital projects, mismanagement, lack of logistics and the inability to expand existing infrastructure to cater for the requirement of potable water. Therefore, most urban and peri-urban dwellers have resulted to groundwater as an alternative water supply.

2.2 Water Policy

The principal objectives of the government's water and sanitation policy are to accelerate the provision of safe water and adequate sanitation facilities and to ensure the sustainable management of those facilities.

The Ghana Water Company Limited is the mandatory organization for the planning, production, managing and implementation of urban water supply systems. Established in 1999 under LI 1648 with the responsibility of urban water supply, the company is unable to achieve 100 percent coverage. As of 2009 the company had achieved 59.98% coverage against a national target of 79.8% (MWRWH, 2009). This shows that the urban water supply is insufficient and there must be review and adjustment in policy to ensure sustainable development.

2.3 Groundwater Quality

Groundwater is globally important for human consumption and any changes or alterations in quality could affect human health. It is also important for the support of habitat and for maintaining the quality of baseflows to rivers (Tay & Kortatsi, 2007). The suitability of groundwater as a source of potable water depends on the measure of its chemical composition. The geochemistry of the soil through which the water flows before reaching the aquifers largely influences the extent of chemical contamination. The dissolution of minerals in the soil and rocks with which the water gets into contact during infiltration determines the chemical composition (Zuane, 1990). The chemistry of groundwater reflects inputs from the atmosphere, soil and water-rocks reactions as well as pollutant sources such as mining, land clearance, agriculture, acid precipitation, and domestic and industrial wastes (Appelo and Postma, 2005). Pollution of water bodies as a result of metal toxicity has become a source of concern among consumers. This concern has become alarming in response to increasing knowledge on their toxicity to human and biological systems (Anazawa *et al.*, 2004).

Groundwater is naturally assumed to be safe for human consumption (Quist *et al.*, 1998). This is because rocks and their derivatives such as soils act as filters. However, this attribute is not always the case because not all soils are effective in this respect. In areas where the materials above the aquifer are permeable and in fractured aquifers pollutants could seep into groundwater bodies. Pathogens such as viruses and bacteria which are very small and contained in polluted substances are known to be transmitted through the soil into groundwater (Lewis *et al.*, 1982).

Natural geochemical and biological as well as anthropogenic impacts on groundwater do not only threaten the quality of human health but also poses a threat to sustainable development and management of groundwater resources (Tay & Kortatsi, 2007).

2.4 Physico-chemical indicators for Water Quality

Physico-chemical parameters and trace elements are mostly used as indices for water quality. The water quality may be described by the physico-chemical and micro-biological characteristics. The water chemistry which consists of dissolved constituents including potassium, bicarbonates, nitrite, sulphate, iron, manganese, fluoride, calcium, magnesium, sodium and chloride occur in the form of electrically charged ions. Other trace elements such as Zinc and Lead may also be found in groundwater.

2.4.1 pH

Hydrogen ion concentration or pH measures the acidity or alkalinity of the water. The pH of water is highly vital for the determination of safe drinking water purposes. Pelig-Ba (1998), reported an average pH value of 7.11 in groundwater in the upper regions of northern Ghana. This average value is well within the range of 6.5 -8.0 recommended by the world health organization (WHO, 2004). In southern Ghana, pH values obtained for groundwater ranged from 6.4 to 6.7 (Tay and Kortasi, 2007). Though pH has no direct effect on human health, all biochemical reactions are sensitive to variations of pH. For most reactions as well as humans, pH of 7 is considered as the best and ideal.

2.4.2 Electrical Conductivity

Conductivity is a measure of the ability of water to conduct electrical current. Conductivity is dependent on the types and concentrations of ion and temperature of water. Total dissolve solids (TDS), a measure of the total ions in water is determined indirectly by the electrical conductivity of the water. Higher TDS influences the suitability of water for potable use. Electrical conductivity is widely used to indicate the total ionized constituents of water. It is an indirect measure of the presence of dissolved solids which could be used as an indicator of water pollution. Human activities also influence water conductivity to some extent. Acid mine drainage, sewage and farm runoff can raise the conductivity levels due the presence of trace metals, other ions, nitrates and phosphate. The WHO recommended limit of conductivity for drinking water is 1000 µS/cm (WHO, 1984).

2.4.3 Iron

Iron in groundwater occurs in nearly all places throughout Ghana. The high concentrations are normally associated with acidic or anaerobic groundwater. According to Ayibotele (1985), about 30% of all boreholes in Ghana have iron problems. Concentrations as high as 57 mg/l have been found in some sources of groundwater in Ghana (Pelig-Ba, 1989). In a related study, iron concentrations in the range of 1-64 mg/l have been observed in all aquifers in the country (WARM, 1998). The high concentration of Fe in groundwater have been partly attributed to the bedrock of aquifers as they have high iron proportions (approximately 6%) and partly to corrosive pump parts (Obuobie and Barry, 2010). High iron concentration affects the aesthetic quality of water. Iron in water can cause yellow, red, or brown stains on laundry, dishes and plumbing fixtures such as sinks. It gives a metallic taste to water and affects foods and beverage. Iron is essential element in human nutrition which gives hemoglobin of blood its red colour and allows blood to carry oxygen.

2.4.4 Manganese

Manganese usually occurs in association with iron, though lower concentrations of the mineral have been observed in the country. However, high concentration of manganese has been found in some communities. In a study conducted in the Densu basin, manganese concentrations above 0.2 mg/l have been observed in some locations (Tay and Kortasi, 2007). High iron concentrations cause unpleasant odour and taste which could lead to problems such as rejection of affected water sources. High iron and manganese concentrations do not have direct health hazards; however concentrations above 0.3 mg/l and 0.1 mg/l for iron and manganese, respectively, causes decolourization of water which results in staining of laundry and sanitary wares (WHO, 2004).

2.4.5 Total dissolved solids (TDS)

The total dissolved solids (TDS) in water constitute mainly carbonates, bicarbonates, chlorides, sulfates, calcium, magnesium, potassium, dissolved metals, dissolved organics and other substances which account for a small portion of the residues in water. Dissolved solids and residues in drinking water tend to change the physical and chemical nature of drinking water (WHO, 2004). Water with high dissolved solids is not preferred by consumers for drinking. The presence of harmful dissolved compounds can be dangerous in water even where the total solid concentration is relatively low with their health effects.

2.4.6 Chlorine

Chlorine as the chloride ion is the major constituent in water and wastewater with a wide range of concentrations from few mg/l in clean rain water to 10 mg/l in supersaturated, hot saline groundwater. An increase of 30 mg/l in the chlorine content in natural waters may be caused by sewage pollution. Health problems of chlorine contamination in drinking water include eye and nose irritation, Anemia in infants and young children and nervous system disorders. Chlorides in groundwater and surface water can be naturally occurring in deep aquifers or caused by pollution from sea water, industrial or domestic waste. Chloride concentrations exceeding 250 mg/l can give rise to detectable taste in water. In metal pipes, chlorides react with metal ions to form soluble salts thus increasing the levels of metals in drinking water. In lead pipes, a protective oxide layer is built up, but chloride enhances galvanic corrosion (Gregory, 1990). It can also increase the rate of pitting corrosion of metals pipes.

2.4.7 Nitrate

Nitrate is an end product of the decay of nitrogenous material such as nitrate fertilizers and animal and human excreta. Its presence in water supply usually denotes bacterial activity as a result of pollution from sewage. Nitrates arise from excessive nitrogen fertilizer application and leachate from sewage systems (Lewis 1982). The nitrite ion contains nitrogen in a relatively unstable oxidation state. Chemical and biological processes can further reduce nitrite to various compounds or oxidize it to nitrate (Anon, 1987). Nitrate is very mobile in groundwater and tends not to adsorb or precipitate on aquifer solids (Hem, 1985; Fytianos and Cristophoridis, 2003). Health hazards of high nitrate level in drinking water include shortness of breath and blue- baby syndrome and other disorders (WHO, 2004).

2.4.8 Calcium

Calcium is obtained from rocks containing limestone and gypsum. Small amounts come from igneous and metamorphic rocks while potassium occurs essentially in rock salt deposits. Wastewater from industries and agricultural practices through excessive use of potash rich fertilizers can also increase the calcium levels in groundwater. Calcium is largely responsible for water hardness and may negatively influence toxicity of other compounds. Calcium carbonate has a positive effect on lead water pipes, because it forms a protective lead (II) carbonate coating. This prevents lead from dissolving in drinking water, and thus prevents it from entering the body. Calcium phosphate is a supporting substance and it causes bone and tooth growth, together with vitamin D. Bones decalcifies (osteoporosis) and fractures become more likely if a body is not getting enough calcium.

2.4.9 Hardness

Hardness is a property of the water that determines its ability to easily form lather with soap. Total hardness is directly related to concentrations of calcium and magnesium. Hard water has high concentrations of calcium and magnesium ions (Ca^{2+} and Mg^{2+}). It is a measure of quantity of divalent ions (salts with 2 positive charges) such as calcium, magnesium and iron in water (Ameyibor and Wiredu, 1991).

These ions enter water supply or groundwater by leaching from minerals within an aquifer. They are generally present as carbonate and bicarbonate salts. Scaling problems in pipes and utensils makes hard water objected by consumers in addition to its health and taste discomfort. Water hardness is measured by adding up the concentration of calcium, magnesium and converting the value to an equivalent concentration of calcium carbonate ($CaCO_3$) in milligram per liter (mg/l) (APHA, 1998).

2.4.10 Phosphate

Phosphate occurs in natural water and is often added in water treatment. Phosphates are 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 distribution systems. Excessive amount constitutes pollution usually by infiltration of wastewater from domestic and industrial sources or agricultural runoff. Phosphorus is often the limiting nutrients for growth of organisms in water. High levels of phosphate can lead to rapid eutrophication especially in lakes and ponds where other nutrients such as nitrate may be present. Such rapid growth in hot climate where the dissolved oxygen in water is already low can create problem of taste and odor (WHO, 2004).

2.4.11 Alkalinity

Alkalinity is important in determining the ability of water to neutralize acid pollution from point sources such as wastewater or rainfall. The alkalinity of water is a measure of its capacity to neutralize acids. Natural waters have some alkalinity and it is nature's means of keeping pH stable. The presence of buffering compounds helps neutralize acids as they are added to water. These buffering compounds are primarily the bases, bicarbonates (HCO_3^-) carbonates (CO_3^{2-}), and hydroxide, borate, silicate, phosphates, ammonium and sulphides. However, the ratio of these ions is a function of pH, mineral composition, temperature and ionic strength. Alkalinity is not considered a health hazard but it is associated with high pH values, hardness and excess dissolved solids. High alkalinity may give water a distinct unpleasant taste.

2.5 Bacteriological indicators for Water Quality

Groundwater obtained from shallow wells is particularly susceptible to contamination from combination of point and diffuse sources (Fuest *et al.*, 1998). Although it is possible to detect the presence of many pathogens in water, the method of isolation and enumeration are complex and time consuming. The difficulty of detecting low concentration of pathogenic bacteria and viruses has become essential for a more practical approach to be adopted. The concept of coliforms as bacteria indicator of microbial water quality is based on the premise that coliforms are present in high numbers in the faeces of humans and other warm blooded animals. Coliform bacteria are grouped and characterized as Total and Faecal coliforms. If faecal pollution has occurred in groundwater, it is likely that these bacteria will be present, even after significant dilution.

Indicator bacteria are bacteria organisms which are always excreted in large numbers by warm-blooded animals, irrespective of whether they are healthy or sick. The presence of indicator organisms is the coliforms (Kool, 1988). The concentration of any given indicator shows the level of risk from associated pathogens.

Faecal indicator bacteria, including *E.coli,* are important parameters for the verification of microbial quality. The presence of faecal coliforms indicates the recent contamination from faecal origin. Faecal coliform bacteria exist mostly in the intestines of warm blooded animals and humans, animal droppings and naturally in the soil. Faecal coliforms are mainly used to indicate the presence of bacteria pathogens such as *campylobacter coli, Yersinia enterocolitica, campylobacter jejuni, Vibro cholera, Salmonella spp, Shigella spp* and pathogenic *E.coli.* These organisms signify the presence of pathogens which may cause water related diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever. Faecal indicator bacteria are also used to measure the sanitary quality for recreational, agricultural, industrial and domestic water supply purposes. Analysis provides a sensitive indication of pollution of drinking water supplies. A variety of simple procedures are available based on the production of acid from lactose or the production of the enzyme β-galactosidase. The procedure includes membrane filtration followed by incubation of the membranes on selective media at 35-37 ^{o}C and counting of colony forming units after 24 hours (WHO, 2006).

Total coliforms do not necessarily indicate recent water contamination by faecal sources; however, the presence or absence of these bacteria in treated water is often used to distinguish the effectiveness of disinfection in water distribution or supply systems. Potential total coliform sources include agricultural runoff, industrial discharges, effluent from septic systems, sewage discharges and infiltration from domestic and wild animal faecal matter (Pritchard *et al.*, 2007). Poor well maintenance, especially shallow dug wells can also increase the risk of bacteria and other harmful organisms getting into a well water supply.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location

The study area, Oti, is located in the Kumasi Metropolis in the Ashanti Region of Ghana. The Kumasi metropolitan area is located between Latitude 6.35’’N and 6.40”N and Longitude 1.30”W 1.35”W. The topography of the area ranges between 250-300 metres above sea level. It covers an area of about 254 square kilometres. The administrative capital of the metropolis, Kumasi, is located in the transitional forest zone and is about 270 km north of the national capital, Accra. The Kumasi metropolitan area is bounded by five districts, namely, Kwabre East to the north, Atwima Nwabiagya to the West, Atwima Kwanwoma to the southwest, Ejisu Juaben to the East and Bosomtwi to the south.

3.1.2 Climate

The average minimum temperature is about 21.5^{o}C and a maximum average temperature of 30.7^{o}C. The metropolis has a double maxima rainfall regime (214.3 mm in June and 165.2 mm in September). The average humidity is about 84.16 per cent at 0900 GMT and 60 per cent at 1500 GMT. The metropolis falls within the moist semi-deciduous South – East Ecological zone. Predominant species of tress found are Ceiba, Triplochlon, and Celtis with Exotic Species. The rich soil has promoted agriculture in the periphery of the metropolis.

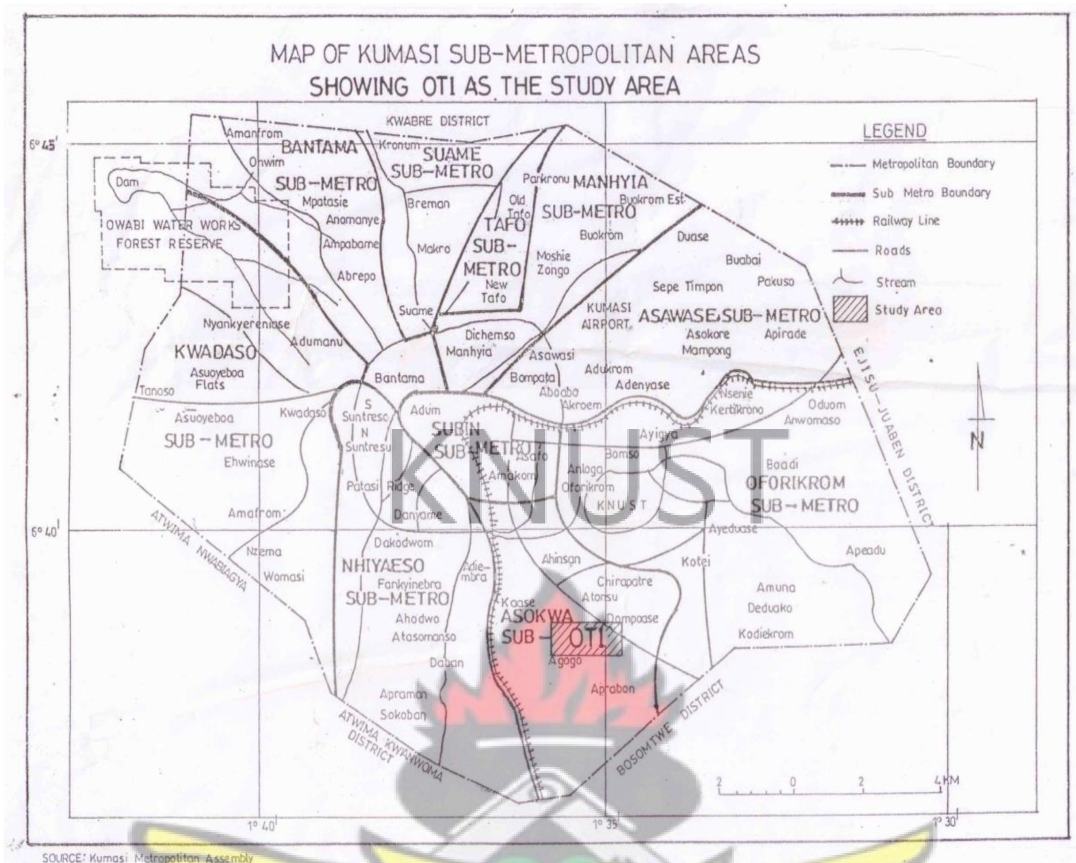

Figure 1: Map of Kumasi Metropolitan Area showing study area.

3.1.3 Demographic Characteristics

The Kumasi Metropolis has a population of 1,170,270 with a growth rate of 5.4% per annum. This accounts for about 32.4% of the population of the Ashanti region (Ghana Statistical Service, 2000). About 39.9% of the population is below 15 years, in contrast to other districts, which range from 40 to 47%. There are more males (51.2%) than females (48.8%) in the metropolis. It has a population density of 5,419 persons per square kilometre. It is estimated that 48%, 46% and 6% of the Metropolis are urban, peri-urban and rural, respectively (KMA, 2010).

3.1.4 Water supply situation

The Kumasi metropolis depends on water supplied from two main sources, the Owabi and Barekese head works. These two together is referred to as the Kumasi Water supply System (KWSS). The Kumasi Water Supply System (KWSS), under the supervision of the GWCL is responsible for the abstraction, production, distribution and revenue collection in the metropolis (Kuma *et al.*, 2010). The total water production target from the system increased from 24.6 Mm^3 in 1996 to 31.1 Mm^3 in 1998 due to major rehabilitation works at the Barekese dam. Water production has therefore remained stable at 32 Mm^3 since 2000 up to date. The treated water from the KWSS is pumped to two reservoirs with a total capacity of 13,800 m^3 where it is monitored. There are approximately 560 km of pipelines which distribute water to the various communities in the metropolis. The quality of water is monitored in a central laboratory in Suame and at 150 other points in the distribution system of KWSS (Blokhuis *et al.*, 2005).

3.1.5 Geological and hydrogeological background

The dominant geological formation in the Kumasi Metropolitan area is the middle Precambrian Rock. The major soil type in the area is mainly the forest Ochrosol. Soils in some peri-urban areas are developed on Granites or Phyllites. Those developed on Granites are acidic whilst those on Phyllites are less acidic. Soil classes found in the Kumasi Metropolis includes Hapli Acrisols, Eutric Gleysols, Gleyic Arenosols and Gleyic Cambisols. The most common soil group is the Ferric Acrisols (Suraj, 2004). The metropolis has an undulating topography and it lies on water shed approximately 282 metres high (Nsia- Gyabaah, 2000).

3.1.6 Study population and sampling sites

The study populations were homes in Oti Township, located within the Asokwa Sub-metro of the KMA. Houses were chosen for the study based on systematic random sampling to ensure that there was equal likelihood of choosing the houses for the study. The sample size was estimated to achieve 95% confidence level, with an expected frequency of wells being 90% and at 5% margin of error.

Using the formula for sample size, $n = \frac{Z^2pq}{d^2}$

For 95% confidence level the value of Z = 1.96

The proportion of wells in houses p=0.9

q=1-0.9 = 0.1

Margin of error d= 0.05

The sample size n= $\frac{1.96^2 \times 0.9 \times 0.1}{0.05^2}$ = 139

A total of 133 out of 139 responded giving a rate of response of 95.6%

24 out of 133, that is 18.1% had wells in their houses.

A total of 24 sampling sites were randomly selected for the purpose of this study. The selection interval was determined by dividing the estimated number of houses (750) in the study area by the estimated sample size (133), giving an interval of 5. A random start point was selected near the primary school and for every fifth house in the east direction a sampling point was chosen. A structured questionnaire was administered to heads of household to collect variables on their demographic characteristics and the use of ground water for domestic purposes. One hundred and thirty three people were interviewed out of which twenty four had wells in their houses.

3.1.6 Sampling collection

Monthly water samples were collected from the wells for a period of three months (October - December, 2012). The samples were taken in the early hours of the day, between 06:00 hrs to 07:00 hrs when the wells were in use by the community. The water from the wells was collected using a sterile bag with about 10 meter long rope. They were collected in 1500 ml sterilized bottles and transported in ice-cold containers to the laboratory for analyses. Two samples of groundwater were collected from each site into clearly labeled bottles, one for physico-chemical analyses and the other for bacteriological analyses. The samples were collected directly from the ground water source without going through the overhead tank.

3.2 Microbial Laboratory Procedure

3.2.1 Preparation of McConkey Broth

In preparing the McConkey broth, 17.5 g of the powder was weighed and dissolved in 500 cm^3 of ionized water. It was mixed well, disposed into tubes, and sterilized for 15 minutes at 121^oC in an autoclave.

3.2.2 Preparation of Tryptophan Broth

Eight grams (8g) of the powder was dissolved in 500 ml of distilled water. It was distributed into containers and sterilized in the autoclave at 121^oC for 15 minutes.

3.2.3 Total and faecal coliforms

Total coliforms and faecal coliforms were analysed using the Most Probable number (MPN) method. Serial dilutions of 10^{-1} to 10^{-8} were prepared by serially diluting 1 ml of the water sample. One milliliter aliquots from each of the dilutions were inoculated into 5 ml of MacConkey Broth with inverted Durham tubes and incubated at 37^{o}C for total coliforms and 44^{o}C for faecal coliforms for 18-24 hours. Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24 hours were identified as positive for both the total and faecal coliforms. Counts per 100 ml were calculated from MPN Tables (Anon, 1992).

3.2.4 *E.coli*

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

3.3 Physico-Chemical Analyses

3.3.1 pH

The pH was determined using a pH meter. An aliquot of 100 ml of the sample was measured into a beaker (500 ml). The pH meter probe was immersed in the water sample. The reading on the pH was recorded after two minutes (Anon, 1992).

3.3.2 Conductivity

The conductivity of the samples was determined using field conductivity meter. The conductivity meter was calibrated by immersing the electrode in a reference buffer of 12,880 µS/cm. when the "Buf" signal was displayed on the screen and blinking the reading was not stable yet until "CON" appeared on the screen. The "CON" key was depressed to confirm for accepting the reading and the equipment was returned to the OPERATION mode for measurement. The electrode of the conductivity meter was raised and replaced in storage – distilled water.

The water sample was out in a beaker and the electrode rinsed with distilled water and lowered into the sample in the beaker. The conductivity in µS/cm of the sample was displayed on the screen and recorded (AHPA, 1998).

3.3.3 Total dissolved solids

A multifunctional HANNA meter (model HI 9032) was used to determine the total dissolved solids of water samples in the laboratory after calibration. About 50 ml of water sample was poured into a clean glass beaker. The electrode was then immersed into the sample and stirred to ensure uniformity. After the reading stabilized the value was read and recorded in mg/l.

3.3.4 Iron concentration

The sample aliquot was digested in nitric acid , diluted appropriately, then aspirated and the absorbance was measured spectrometrically at 248.3 nm with the aid of a UNICAM

969 SOLAAR 32 Atomic Absorption Spectrophotometer and compared to identically prepared standard and blank solutions, using an air-acetylene oxidizing flame.

3.3.5 Calcium Determination

A 100 ml of the water sample was put into a 250 ml conical flask. Four (4) ml sodium hydroxide solution was added to the contents of the flask followed by the addition of about 0.2 g murexide indicator. The content in the conical flask was titrated against 0.02 M EDTA to end point. This is indicated by a pink colouration. Titration was repeated until a consistent titre was obtained (APHA, 1998).

Calcium Hardness as CaCO3 (mg/l) = average Titre Value × 20

Total hardness determination:

A 100 ml of the water sample was put into a 250 ml conical flask and 10 L ammonium chloride buffer added to the contents in the conical flask. Two drops of Erichome Black T indicator was added. The content in the conical flask changed from wine or red to blue at the end point. Titration was repeated until a consistent value was obtained. The value of the average titre was recorded (APHA, 1998).

CALCULATION: Total hardness, as CaCO3 (ml/l) =titre value × 20

3.3.6 Chlorine

Argentometric method was used to determine the chloride concentration in water samples. Potassium chromate indicator solution was prepared by dissolving 50 g of K_2CrO_4 in a little distilled water and 1 M $AgNO_3$ solution was added until a definite precipitate was formed. The solution was allowed to stand for 12 hours, after which it was filtered and diluted to 1000 ml. The silver nitrate titrant solution (0.0141 M) was prepared by dissolving 2.395 g $AgNO_3$ in distilled water and diluted to 1000 ml. Using pipette , 50 ml of water sample was poured into a clean conical flask. Then 1 ml of 5% potassium chromate (K_2CrO_4) indicator was added. This was titrated against 0.0141 M $AgNO_3$ solution, with gentle swirling until the colour changed from yellow to brick red. The titre was read and recorded in millimetres. The concentration of chloride was calculated as:

$$Cl^- (mg/L) = \frac{(A-0.2)\times 0.5\times 1000}{sample\ Volume\ (ml)}$$

where

A= Titre value

3.3.7 Phosphate

Palintest photometer (model 5000) was used to determine phosphate after the meter was calibrated. A clean test tube was filled with water sample to the 10 ml mark. One tablet each of phosphate No. 1 LR and No. 2 LR were added, crushed and dissolved. The mixture was allowed to stand for ten minutes for full colour development. The test tube was inserted into the chamber and wavelength of 640 nm was selected and the sample transmittance (%T) read. The corresponding concentration on the phosphate LR calibration chart was read and recorded in mg/l.

3.3.8 Nitrate determination

The nitrate test tubes (comparator cell) for the various water samples were raised several times with the samples and filled to the upper 10 ml mark. 10 drops of nitrate-1 were added to the samples and shaken to mix. One level spoonful of nitrate-2 was then added to the sample. The screw caps were replaced and the samples were well shaken for 15 to 30 seconds. The tubes were allowed to stand for one minute and inverted three to five times to facilitate flocculation. The solution was allowed to stand for five minutes to allow for full colour development. The photometer readings were taken using photometer (PF-10/PF-11) and compared with Nitrate calibration chart.

CHAPTER FOUR

RESULTS

4.1 Introduction

In this chapter the results of water analyses conducted on the selected wells within the community are presented.

4.2 Physico-chemical properties

The physico-chemical properties of water describe the nature or the characteristics (physical and chemical) of the water. Parameters such as electrical conductivity, pH, total dissolved solids, salinity, total hardness, calcium, iron, chlorine, phosphate and nitrate were analysed. The results of the analyses are presented in Tables 1 and Table 2.

4.2.1 pH

The mean pH values obtained ranged from 5.41±0.53 to 6.54±0.41. WL10 had the lowest mean pH while WL13 had the highest mean pH (Table 1). The mean pH values recorded for all the wells sampled in the community fell below the recommended GWC and WHO standards with the exception of WL13 which fell within the recommended range of 6.5 – 8.5.

4.2.2 Conductivity

The mean conductivity values of the wells ranged from 0.05±0.01 to 0.36±0.05. The conductivity of the groundwater was highest at WL12 with the mean value of 0.36±0.05 whiles the lowest values were recorded at WL3, WL5, WL8, WL9 and WL14 (Table 1).

Table 1: Physico-chemical properties of the well water samples

Sample ID	Conductivity (µS/cm)	TDS (mg/l)	pH	Salinity (mg/l)	Total Hardness (mg/l)
WL1	0.06±0.02	0.03±0.01	6.02±0.19	0.05±0.02	60.00±0.82
WL2	0.14±0.01	0.65±0.17	5.87±0.19	0.04±0.02	48.00±0.82
WL3	0.05±0.01	0.04±0.02	5.97±0.22	0.05±0.02	62.00±2.45
WL4	0.16±0.03	0.07±0.02	5.86±0.33	0.07±0.02	84.00±4.08
WL5	0.05±0.02	0.05±0.02	5.89±0.43	0.05±0.02	53.00±1.15
WL6	0.29±0.16	0.24±0.10	5.89±0.42	0.31±0.11	120.13±0.63
WL7	0.17±0.03	0.07±0.02	6.02±0.21	0.04±0.01	37.00±1.15
WL8	0.05±0.01	0.04±0.01	5.79±0.46	0.04±0.01	47.13±1.11
WL9	0.05±0.01	0.04±0.01	5.42±0.49	0.03±0.01	64.25±0.50
WL10	0.14±0.05	0.64±0.01	5.41±0.53	0.04±0.01	44.00±0.82
WL11	0.09±0.01	0.06±0.12	6.12±0.67	0.04±0.01	55.50±0.58
WL12	0.36±0.05	0.24±0.10	5.63±0.28	0.21±0.10	121.00±2.00
WL13	0.12±0.01	0.70±0.07	6.54±0.41	0.05±0.01	42.63±1.25
WL14	0.05±0.01	0.04±0.02	5.89±0.12	0.06±0.07	36.50±1.29
WL15	0.82±0.09	0.05±0.01	5.96±0.30	0.04±0.01	45.75±0.50
WL16	0.15±0.03	0.05±0.01	5.82±0.15	0.04±0.02	63.50±1.00
WL17	0.15±0.04	0.04±0.01	5.90±0.15	0.03±0.01	53.88±1.03
WL18	0.20±0.07	0.06±0.01	6.30±0.45	0.03±0.01	50.75±0.87
WL19	0.11±0.03	0.16±0.20	5.93±0.13	0.05±0.01	36.13±0.25
WL20	0.06±0.01	0.06±0.01	6.34±0.39	0.05±0.01	47.00±0.41
WL21	0.27±0.30	0.10±0.13	5.60±0.22	0.07±0.09	71.25±0.96
WL22	0.09±0.04	0.06±0.02	5.74±0.23	0.04±0.02	49.13±0.85
WL23	0.27±0.31	0.06±0.01	5.81±0.38	0.06±0.01	41.25±0.96
WL24	0.09±0.02	0.06±0.02	6.05±0.50	0.04±0.01	43.50±0.58
GWC	**300**	**1000**	**6.5-8.5**	**300**	**500**
WHO	**300**	**1000**	**6.5-8.5**	**300**	**500**

4.2.3 Salinity

Salinity values ranged from a minimum mean of 0.03±0.01 to a maximum mean value of 0.29±0.01 at WL9 and WL12, respectively (Table 2). The conductivity values for the samples were all below the recommended WHO /GWC standard of 300 µS/cm for drinking water.

4.2.4 Total dissolved solids (TDS)

According to Table 1, highest TDS for the samples was obtained at WL13 with the mean value of 0.70±0.07 whiles minimum values were recorded for wells WL3, WL8, WL9, WL14 and WL17 with TDS value of 0.04±0.01. These values fell within the WHO and GWC standards for drinking water.

4.2.5 Total Hardness

The mean total hardness recorded for the water samples ranged from 36.13±0.25 to 121.00±2.0. These were recorded at WL19 and WL12, respectively. These mean values were below the recommended GWC / WHO standards of 500 mg/l for drinking water purposes (Table 1).

4.2.6 Iron

Iron concentration in the sampled water ranged from 0.11±0.01 to 0.68±0.58. High iron concentrations (> 0.3 m/l) were recorded in WL6, WL10, WL14, WL22, WL23 and WL24 (Table 2). With the exception of these wells, values for the other remaining wells were within the recommended 0.3 mg/l threshold limit set by WHO and GWC for drinking water purpose.

Table 2 Levels of nutrients and metals in the water samples

Sample ID	Iron (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)	Calcium (mg/l)	Chloride (mg/l)
WL1	0.23±0.02	2.53±0.84	2.16±0.02	4.48±0.03	2.16±0.05
WL2	0.21±0.01	3.61±0.54	2.45±0.04	4.43±0.04	3.50±0.49
WL3	0.11±0.01	3.96±0.55	2.37±0.08	1.42±0.02	5.62±0.13
WL4	0.18±0.01	6.01±0.55	2.17±0.22	6.21±0.18	5.40±0.23
WL5	0.12±0.01	3.31±0.35	2.59±0.10	0.95±0.04	22.35±0.24
WL6	0.56±0.03	3.18±0.57	4.26±0.18	29.22±0.18	2.67±0.06
WL7	0.24±0.04	4.11±0.69	3.14±0.03	2.92±0.10	6.44±0.10
WL8	0.20±0.02	4.43±0.01	1.80±0.07	3.18±0.01	13.29±0.25
WL9	0.18±0.01	2.95±0.57	1.78±0.07	2.81±0.04	21.36±0.43
WL10	0.32±0.02	2.64±0.33	2.47±0.18	2.97±0.05	8.28±0.63
WL11	0.30±0.01	4.45±0.71	3.13±0.06	1.41±0.39	9.31±0.29
WL12	0.25±0.01	3.50±0.40	4.52±0.31	3.72±0.02	8.99±0.18
WL13	0.25±0.02	4.20±0.23	2.30±0.36	3.54±0.03	11.09±0.46
WL14	0.68±0.58	3.65±0.06	1.53±0.05	2.31±0.05	14.31±0.39
WL15	0.11±0.01	4.06±0.12	2.54±0.26	1.42±0.02	5.49±0.17
WL16	0.18±0.01	3.35±0.36	1.87±0.06	2.69±0.06	20.62±0.75
WL17	0.11±0.01	4.42±0.83	2.47±0.13	1.39±0.04	5.61±0.26
WL18	0.13±0.01	3.40±0.47	2.84±0.05	0.95±0.03	20.37±0.34
WL19	0.18±0.01	3.50±0.59	1.50±0.07	2.30±0.03	13.54±0.43
WL20	0.21±0.01	3.99±0.41	1.74±0.07	3.16±0.04	12.24±0.31
WL21	0.11±0.01	1.44±0.06	3.03±0.01	0.53±0.01	3.05±0.33
WL22	0.52±0.10	0.80±0.12	2.33±0.78	7.86±0.58	1.26±0.04
WL23	0.52±0.08	0.12±0.40	3.98±0.58	3.82±0.03	1.94±0.52
WL24	0.62±0.50	1.17±0.09	2.30±0.71	6.23±0.16	3.21±0.48
GWC	0.3	50	400	200	250
WHO	0.3	50	400	200	250

4.2.7 Nitrate

Table 2 indicates that nitrate concentration ranged from 0.12±0.4 mg/l to 6.01±0.55 mg/l. The highest nitrate concentration was recorded at WL4 whiles the corresponding minimum nitrate concentration was recorded at WL23. The mean nitrate–nitrogen for the investigated waters was within the recommended WHO / GWC standard of 50 mg/l for drinking water.

4.2.8 Phosphate

The highest Phosphate concentration was recorded at WL12 with mean value of 4.52±0.31 mg/l while the minimum was recorded at WL19 with mean value of 1.50±0.07 mg/l. The levels of phosphate were far below the recommended WHO guideline of 400 mg/l for drinking water purposes.

4.2.9 Calcium

Calcium concentration also ranged from 0.53±0.01 mg/l to 29.22±0.18 mg/l for the investigated waters. The minimum value was recorded at WL21 with the corresponding highest value being recorded at WL6. The calcium concentrations were all below the recommended WHO guideline limit of 200 mg/l for drinking water purposes.

4.2.10 Chloride

In the study, chloride concentration was found to be in the range of 1.26±0.04 mg/l to 22.35±0.24 mg/l. The highest concentration was recorded at WL5 whiles the corresponding lowest value was found at WL22. The chloride levels were all below the recommended WHO guideline limit of 250 mg/l for drinking water purposes.

4.3 Microbial Parameters

The results of the microbial analyses of the well water samples are presented in the Table 3 below.

Table 3: Results of the microbial analyses for well water sample.

Sample ID	Total Coliform (MPN/100 ml)	Faecal Coliform (MPN/100 ml)	*E. coli* (MPN/100 ml)
WL1	0	0	0
WL2	9.15×10^{5}	9.00×10^{4}	4.00×10^{4}
WL3	2.35×10^{6}	2.30×10^{5}	3.00×10^{4}
WL4	4.15×10^{5}	4.00×10^{4}	0
WL5	9.15×10^{5}	4.00×10^{4}	0
WL6	2.30×10^{5}	3.00×10^{4}	0
WL7	9.15×10^{5}	9.00×10^{4}	4.00×10^{4}
WL8	2.35×10^{6}	2.30×10^{5}	0
WL9	4.15×10^{5}	9.00×10^{4}	3.00×10^{4}
WL10	9.15×10^{5}	4.00×10^{4}	3.00×10^{4}
WL11	4.15×10^{5}	9.00×10^{4}	0
WL12	9.15×10^{5}	4.00×10^{4}	0
WL13	4.0×10^{4}	0	0
WL14	0	0	0
WL15	9.20×10^{5}	9.20×10^{4}	3.90×10^{4}
WL16	4.20×10^{5}	0	0
WL17	3.10×10^{5}	3.00×10^{4}	0
WL18	4.20×10^{5}	4.20×10^{4}	0
WL19	2.20×10^{5}	3.10×10^{4}	0
WL20	2.70×10^{5}	3.10×10^{4}	3.00×10^{4}
WL21	5.90×10^{5}	3.70×10^{4}	3.00×10^{4}
WL22	3.30×10^{5}	2.80×10^{4}	0
WL23	4.20×10^{5}	3.50×10^{4}	0
WL24	3.20×10^{5}	4.00×10^{4}	0
GWC	**0**	**0**	**0**
WHO	**0**	**0**	**0**

4.3.1 Total coliforms

Total coliforms were present in all the samples with the exception of WL1 and WL14. The mean total coliform count for the wells ranged from 3.2×10^{5} MPN/100 ml to 2.35×10^{6} MPN/100 ml (Table 3).

4.3.2 Faecal coliforms

Faecal coliforms were present in all the samples except WL1, WL13, WL14 and WL16 which recorded zero counts of faecal coliforms. The mean values for faecal coliform ranged from 2.8×10^{4} MPN/100 ml to 2.35×10^{5} MPN/100 ml (Table 3).

4.3.3 *E.coli*

According to Table 3, *E.coli* counts in the various wells were minimal among the wells. *E.coli* counts were present in eight of the wells with mean values ranging from 3×10^{4} MPN/100 ml to 4×10^{4} MPN/100 ml.

CHAPTER FIVE

DISCUSSION

5.1 Physico-chemical Parameters

5.1.1 pH

The mean pH values indicate that the well water samples were slightly acidic (Table 1). The low pH has a potential to enhance corrosion but may not affect its use for domestic purposes. Low pH values may be as a result of the production of CO_2 from microbial respiration, which leads to the lowering of the pH of the water (Pelig-Ba *et al.*, 1991). The low pH could be attributed to the type of soil and the material used in construction of the wells. The soil type may have low levels of dissolved CO_3^{2-} and HCO_3^- , which lowered the pH of the groundwater.

Nkansah *et al*. (2010), in a related study on groundwater in the Kumasi metropolis found mean pH values of 6.3 to 7.7 which were within the recommended WHO and GWC permissible limits. However, lower mean pH values of 4.64 to 5.39 have been found in well waters within some peri-urban communities in the Kumasi metropolis (Boamah *et al.*, 2011). Lower pH levels in the range of 5.1 to 6.8 have also been recorded in some selected boreholes in other parts of the region (Nkansah *et al*., 2009). Ewusi *et al.* (2012), found mean pH values of 4.7 to 7.1 in some selected wells within the Obuasi metropolis. Although the permissible pH limit is 6.5-8.5, pH levels of 5 are still permissible by the GWC.

5.1.2 Conductivity

Electrical conductivity is a determinant of the ionic concentration of water. The mean conductivity values measured among the wells were within the recommended WHO and GWC permissible limit of 1500 µS/cm (Table 1). The low conductivity values obtained indicate that the well waters might have low concentration of dissolved ions. Whiles there is little health risk associated with this parameter, high EC values are associated with the poor taste of water which influences the dissatisfaction and complains from most water consumers. Conductivity values have been found to be in the acceptable WHO prescribed limits for hand dug wells in some peri-urban communities within the Kumasi metropolis. Electrical conductivity values ranging from 68.75±0.36 µS/cm to 258±0.41 µS/cm have been recorded in well waters within the metropolis (Boamah *et al.*, 2011). In a related study within some parts of the region, mean conductivity values were also found to be in the WHO and GWC acceptable limits for drinking water purposes (Nkansah *et al.*, 2011). Denutsui *et al.* (2012) reported elevated levels of EC in groundwater near an unlined municipal landfill. Electrical conductivity values ranging from 3120 µS/cm to 7890 µS/cm which are far above the recommended permissible limits as compared to the conductivity levels obtained in this study. This high conductivity obtained is an indication of the amount of dissolved materials as a result of leachate percolation. The results obtained for conductivity in this study (Table 1), clearly shows the influence of the landfill on its low contamination potential.

5.1.3 Total Dissolved Solids (TDS)

The levels of mean Total dissolved solids obtained from the well water samples were all within the acceptable limit of 1000 mg/l prescribed by WHO and GWC, and hence, do not pose a health risk to consumers (Table 1). The mean TDS recorded in the study ranged from 0.01±0.13 mg/l to 0.70±0.07 mg/l. In the same geographical area, TDS levels' ranging from 68.25±0.51 mg/l to 214.25±1.02 mg/l has been recorded for some selected hand dug wells (Boamah *et al.*, 2011). In a similar study, total dissolved solids within the range of 6.0±16 mg/l to 230±4 mg/l have been reported in some selected hand dug wells within the Kumasi metropolis (Nkansah *et al*., 2010). However, Denutsui *et al*. (2012), in a related study found remarkably high TDS concentrations at the Oboglo municipal landfill site in Accra. The range of TDS values were between 1611 mg/l and 3940 mg/l which were far above the recommend permissible. This high value of TDS may be attributed to the leaching of various compounds in to the unsaturated zone water as a result of the presence of the unlined landfill operation. Groundwater pollution detected through increased TDS concentration (318mg/l to 2007mg/l) has been reported near the vicinity of other dumping sites (Acheampong *et al*., 2013). This high value is an indication of is effects on the water quality.

TDS is more of aesthetic rather than a health hazard. Elevated concentration of TDS above 1000 mg/l is an indication of high mineral content which gives water an unpalatable taste (Al-Ruwiah *et al.*, 2010). High TDS produce bad odour, colour and may contribute to induced physiological reaction in the consumer (Spellman and Drinan, 2000).

5.1.4 Total hardness

Results of the study shows that mean total hardness ranged from 36.13±0.25 mg/l to 121±2.0 mg/l in the water samples. The levels were within the WHO and GWC recommended levels in drinking water. The WHO (1998), has classified water with a total hardness of $CaCO_3$ < 50 mg/l as soft water; 50 mg/l to 150 mg/l as moderately hard water, and 150 mg/l and above as hard water. Based on this classification, groundwater in the study area is mostly soft to moderately hard; thus it is suitable for domestic purposes in terms of hardness. The levels of total hardness obtained in this study were lower compared with those obtained for some selected wells within the Kumasi Metropolis by Nkansah *et al.* (2010). Ewusi *et al*. (2012), found total hardness values for some selected groundwater samples to be in the acceptable limits within other parts of the region. Nkansah and Ephriam (2009), in a related study also found equally satisfactory total hardness in the range of 3 to 402 mg/l in some groundwater samples within the region. Total harness causes poor lather formation by soaps by forming a solid precipitate instead of forming lather (Ameyibor and Wiredu, 1991). High levels of total hardness in water may affect the taste but does not pose any health risk to consumers. The hardness of the water may be due to the leaching of Ca and Mg ions into the groundwater. Boiling of water at boiling temperature will naturally remove temporary harness whiles addition of carbonates and sulphates will eliminate permanent hardness (Akinbile and Yusoff, 2011).

5.1.5 Iron

Total iron concentration in the investigated samples was generally high with the levels in some of the wells exceeding the WHO guideline value of 0.3 mg/l. The iron concentration ranged from 0.11±0.1 mg/l to 0.68±0.58 mg/l. Out of the total of twenty four wells sampled, six wells (25%) recorded elevated iron concentrations that were above the recommended limit set by WHO and GWC (Table 2). It is generally observed that high levels of iron are associated with most groundwater in Ghana (Pelig-Ba *et al.*, 1991). High iron concentration is mostly associated with relatively shallower wells and boreholes (< 40 m deep) as concentration in deeper boreholes (> 40 m deep) are observed to be low (Bolaji and Tse, 2009).

Elevated levels of iron above the recommended limits set by WHO and GWC has been reported in some selected hand dug wells and boreholes in both the Kwahu West and Bosumtwi-Atwima-Kwanwoma Districts which agree with the results obtained in this study (Nkansah and Ephriam, 2009) and Nkansah *et al*., 2011. On the other hand, lower levels of iron have been reported elsewhere in the metropolis by Nkansah *et al*. (2010).

Although high iron concentration may not pose a health hazard to consumers, the occurrence of yellowish brown colouration may result in the rejection of water from these wells by consumers. High iron concentrations are known to cause unpleasant taste and odour. Water with high concentrations of iron may cause the staining of plumbing fixtures and laundry. The presence of iron could be attributed to the weathering of minerals in the underlying bedrock.

5.1.6 Nitrate

The mean nitrate concentrations for the investigated wells were low, and were within the recommended limit set by the WHO and GWC for potable water purposes (Table 2). Although the concentrations were generally low, its presence in all the wells suggests other anthropogenic influence, probably from leaching or run-off from agricultural fields or contamination from human or animal waste. Sources of nitrate in groundwater have been attributed to runoff from agricultural lands and contamination from human or animal waste (WHO, 2004). They also include natural geologic deposit and mineralization of soil organic nitrogen (Hallerg and Keeney, 1993).

The presence of nitrates in the investigated waters connotes pollution hence such groundwater will require treatment before use. Perhaps this could be attributed to leakage from septic tanks in most houses and leachate from the landfill which is a unique anthropogenic activity in the area. In a related study high nitrate levels (30 mg/l to 60 mg/l) far above the recommended permissible limits were recorded in groundwater near landfill sites as a result of leachate percolation (Akinbile and Yusoff, 2011).

Low nitrate levels in groundwater such as reported in this study have also been reported in similar settings by several authors. These include studies by Akoto and Adiyia (2008), Nkansah and Ephraim (2009) and Tiimub *et al*. (2012).

On the other hand, higher nitrate levels up to 4625 mg/l have been reported in the Ga East municipality of Ghana by Ackah and Anim (2011). Also, Tay (2004), found elevated nitrate levels far above the WHO and GWC recommended limits for drinking water purposes in some wells in southern Ghana. Excessive nitrate contents in drinking water can cause health disorders such as methemoglobinemia, goitre and hypertension (Baird and Cann, 2004).

5.1.7 Phosphate

The variation in phosphate concentration rangd from 1.5±0.07 mg/l to 4.5±0.31 mg/l for the well water sampled in this study (Table 2). Phosphate concentration obtained in the study were below the WHO and GWC guidline of 400 mg/l. The potential sources of phosphate are sewage, fertilizer, animal waste and plant remains (Salvato *et al.,*2003). The presence of high levels of phosphate concentration in natural waters could be attributed to infiltration of contaminant from antropogenic souces. Phosphate is an essential nutrient and another indicator of anthropogenic biological pollution (Addo *et al.,* 2011). The mean phosphate concentrations obtained in this study do not pose any health risks to consumers. Phoshpate concentrations ranging from 0.33 mg/l to 9.30 mg/l have been recorded for some selected groundwater samples within the Kumasi metropolis which are in conformity to the results obtained in this study (Nkansah *et al.,* 2010). The phosphate concentrations obtained in this study were very low possibly because of phosphate adsorption by soils in the area (Ewusi *et al.,* 2012) . Other contributing factor could be the limiting factor of nutrients for algal growth in water (Karikari *et al.,* 2007). Addo *et al.* (2011), recorded similar lower phosphate levels in some selected wells in south-east Ghana . Tiimub *et al.* (2012), in a related study of some selected groundwater samples in Nkawkaw also reported lower phosphate concentrations which were within the acceptable limits set by WHO and GWC.

5.1.8 Calcium

The mean calcium concentrations for the investigated wells ranged from 0.53±0.01 mg/l to 29.22±0.18 mg/l (Table 2). The concentrations of calcium obtained were all below the recommended WHO guideline limit of 200 mg/l for drinking water purposes. The range of calcium concentration obtained in this study were similar to what Ewusi *et al.* (2012), reported but were higher than those reported by Nkansah *et al.* (2010). Ackah *et al.* (2011), also recorded calcium levels in the range of 0.39mg/l to 9.97 mg/l in the Ga East municipality of the Greater Accra Region of Ghana. In related study calcium levels in groundwater near municipal landfill were found within the recommended limits. Mean calcium level of 93.88 mg/l was found in groundwaters near a municipal landfill site which is far below the recommended permissible limits for potable water (Acheampong *et al*., 2012).

Calcium is an essential element needed by the human body for teeth and bone formation. It also plays an important role for heart and muscle contractibility and also for blood coagulability. Calcium dificiency in children causes rickets, the condition of under mineralised bones resulting in structural deformities of growing bones. The presence of high calcium levels above recommeded limits presents danger of hardness in water. The net effect is that forming lather with soap becomes a major challenge for domestic users.

5.1.9 Chloride

The acceptable recommended level for chloride concentration in drinking water is within 250 mg/l (WHO, 1997). The chloride levels for all the wells sampled were within this limit. The mean chloride concentration for the investigated waters ranged from a minimum of 1.26±0.04 mg/l to a maximum of 22.35±0.24 mg/l (Table 2). The total Chloride levels obtained were also within the acceptable limit of 250 mg/l prescribed by the GWC standards. Chloride levels obtained in this research conforms to those obtained by Nkansah *et al.* (2010). Chloride levels within the acceptable limits have also been found in some selected groundwater sources in other parts of the Ashanti Region although slightly higher than those obtained in this study (Nkansah and Ephriam, 2009).

Chloride in groundwater and surface water is attributed to both natural and anthropogenic sources. These sources include leachates from landfill and septic tanks, the use of inorganic fertilizers, and run off containing road de-icing salts (Tiimub *et al.*, 2012).). High chloride levels within the range of 362 mg/l to 589 mg/l in groundwater have been found near municipal landfills site compared to the results obtained in this study. The high chloride content was as a result of percolation of leachates from uncontrolled waste dumps which kept increasing with time (Bhalla *et al.*, 2013).

Chloride ions are non-cumulative; however, excessive intake over longer periods poses a serious health hazard (Dallas and Day, 1993). Although there is no health based guideline for chloride, excess concentration of chloride may cause skin irritation and damage to water equipment including water heaters (Tiimub *et al.*, 2012). Total chloride indicates the level of salts in water and occurs in the form of NaCl. A higher chloride level in drinking water therefore gives it a salty taste and has a laxative effect on people.

5.2 Microbial Parameters

5.2.1 Total coliorms

Total coliforms were present in all the wells sampled (except WL1 and WL14), and the levels exceeded the WHO / GWC recommended guideline value of 0.0 MPN per 100 ml in drinking water (Table 3). The presence of total coliforms is an indication that these wells have the capacity to transmit water related diseases such as cholera, dysentery and diarrhea. The presence of Total coliforms in well waters is due to the poor insanitary conditions and practices in and around the wells. The most common receptacles for lifting water are locally fabricated rubber with metal necks usually fitted to a nylon robe. They are often either left in muddy surroundings of the well or coiled into the rubber containers which are left on the wells when not in used. These poor unhygienic practices could lead to the introduction of microbial contaminants into the wells.

The presence of total coliforms has been recorded in wells and boreholes in many other studies in the country. Obiri –Danso *et al*. (2009), have reported high total coliform counts in the range of 3×10^1 to 3×10^8 MPN per 100 ml among some wells and boreholes in peri–urban Kumasi. Similar results have also been reported in the Achiase and Wabiri communities in the Ejusu Juaben municipality by Tiimub *et al*. (2012); and another by Tiimub *et al.* (2008), in the Bawku East District.

5.2.2 Faecal coliforms

The mean values for faecal coliforms ranged from 2.3×10^4 to 9.20×10^5 MPN per 100 ml (Table 3). The presence of faecal coliforms is an indication that most of these wells are contaminated by pollution source. The proximity and location of the wells to latrines in most houses may have contributed to the faecal contamination. Most of these wells were situated within the household with lateral distances which were much closer to pit latrines, soakage pits and septic tanks. The quality of such groundwater located less than 10 metres could easily be influenced by the lateral flow of pollutants into the water body. Adekunle *et al*. (2007), observed that siting wells farther away from dumping sites and defecation sites has a profound effect on the reduction of both total and faecal coliforms. Dzwairo *et al.* (2006), in a related study also observed that groundwater quality could be affected by pit latrines up to about 25 m from the pit latrines.

Quist (1999), found the presence of faecal coliforms in most wells within the Kumasi peri-urban areas. In a similar study, significant levels of faecal coliforms ranging from 3×10^1 to 3.5×10^7 MPN per 100 ml were recorded among some selected wells in some peri-urban areas in the Kumasi metropolis (Obiri- Danso *et al.,* 2009). Boamah *et al*. (2011) also found significant faecal coliform levels within the range of 4.88×10^2 to 8.53×10^2 MPN per 100 ml for some selected hand dug wells within the same geographical area. Similarly, substantial higher levels of faecal coliforms have been recorded in some selected hand dug wells in some peri-urban communities in the Kumasi metropolis which were above the recommended guideline limit for potable water (Akple *et al.,* 2011).

5.2.3 *E.coli*

The presence of *E.coli* in the well waters is an indication of contamination by faecal matter. High levels of *E.coli* are present in both animal and human faeces (WHO, 2004). Their presence in water is an indication that other enteric pathogens are also present in the water. This poses a potential health risk to households that depend on these untreated water sources for domestic purposes.

The mean *E.coli* counts in the selected wells range from $3\times10^4 \pm0.0^7$ MPN per 100 ml to $4\times10^4 \pm0.0^7$ MPN per 100 ml (Table 3). There was minimal detection of *E.coli* in well waters sampled. Out of the total of 24 selected wells sampled, *E.coli* was present in only eight (or 25%) of the wells (Table 3). In a related study, Nkansah, *et al.* (2010), recorded

E.coli counts below the Minimum Detection Level of 20 MPN/100 ml in the Kumasi metropolis for some selected wells which contradicts the recorded *E.coli* counts among the eight wells in this study.

Tiimub *et al.* (2012), in a related study also isolated some significant levels of *E.coli* in some selected wells within the Bawku Municipality which were far above the recommended WHO / GWC guideline limit. Pritchard *et al.* (2008), and Adekunle *et al*. (2007), have also recorded high *E.coli* levels in well waters in Malawi and Ilorin in Nigeria, respectively compared to the *E.coli* levels obtained in this study.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study showed that the groundwater sampled in the Oti community was mostly acidic with pH values far below the recommended Ghana Water Company and WHO recommended permissible levels for drinking water. Other physico-chemical parameters such as electrical conductivity, total hardness, and total dissolved solids were all within the recommended limits. However, iron levels recorded for some of the wells were above the permissible levels for drinking water.

The presence of bacteriological contaminants (Total Coliforms, Faecal Coliform and *E.coli*) in almost all the wells sampled within the study area indicates faecal contamination. Consumption of water from these wells without any form of treatment poses a serious health concern. Consumers could easily be affected by water-borne diseases such as diarrhoea, cholera and dysentery. However, it could be used for other domestic purposes.

6.2 Recommendations

The health risk associated with the groundwaters observed in this study poses a serious threat to consumers and as such it is recommended that;

1. The water from these wells may require treatment such as boiling or treatment with hypochlorite solution since that could kill most pathogens before drinking.

2. Windlass should be mounted on the wells to improve the hygienic conditions of the wells. This will help prevent various receptacles with varying degrees of hygiene from being used on the well.

3. The wells should be protected enough from external contamination such as run-offs by providing adequate covers and raising it 1 m above the ground.

4. More work need to be done in this area by extending the area of research to include the whole geographical area in order to ascertain the extent of conformity of ground water to WHO and GWC safety standards for drinking purposes.

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APPENDICES

APPENDIX 1: Ghana Water Company and WHO permissible guideline limits for some Physico-chemical and microbiological parameters

PARAMETER	WHO GUIDELINE	GWC GUIDELINE
pH	6.5-8.5	6.5-8.5
Electrical Conductivity (μS/cm)	300	300
Total Dissolved Solids (mg/l)	1000	1000
Total Hardness (mg/l)	500	500
Salinity (mg/l)	300	300
Iron (mg/l)	0 - 0.3	0 - 0.3
Nitrate (mg/l)	10	10
Phosphate (mg/l)	400	400
Calcium (mg/l)	200	200
Chloride (mg/l)	250	250

Appendix 2: Microbiological Parameters

PARAMETER	WHO GUIDELINE	GWC GUIDELINE
Total coliforms	0.0 counts per 100 ml	0.0 counts per 100 ml
Faecal Coliforms	0.0 counts per 100 ml	0.0 counts per 100 ml
E.coli	0.0 counts per 100 ml	0.0 counts per 100 ml