QUALITY OF SACHET WATER SOLD IN THE TECHIMAN MUNICIPALITY

BY

OWUSU ANSAH DERKYE

(BSc. APPLIED BIOLOGY)

A Thesis Submitted to the Department of Theoretical Applied Biology, College of Science, In Partial Fulfillment of the Requirement for the Award of the Degree of Master of Science in Environmental Science

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI- GHANA

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

COLLEGE OF SCIENCE

NOVEMBER, 2015.

DECLARATION

I hereby declare that this submission is my own work, 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.

Owusu Ansah Derkye   -----------------------------   ----------------------

(Student Name & ID)   Signature   Date

(PG 6505611)

Certified by:

Dr. M. G. Addo   -----------------------------   ----------------------

(Supervisor)   Signature   Date

Certified by:

Dr. I.K. Tetteh   -----------------------------   ----------------------

(Head of Department.)   Signature   Date

ABSTRACT

The quality of sachet water sold in the Techiman Municipality was determined. Ten different brands out of twenty sachet water sold in the Techiman Municipality in the Brong Ahafo region were purposively selected for the study. These were: WA_1, WA_2, WA_3, WA_4, WA_5, WA_6, WA_7, WA_8, WA_9 and WA_{10}. Triplicate samples were taken from both production and retail points/sources over a period of three (3) months, starting from February, 2013 to April, 2013. A total of sixty (60) samples were taken for the period of the study. Physiochemical parameters such as pH, Electrical Conductivity (EC), Alkalinity, Colour, Total Suspended Solids (TSS), Turbidity, Total Hardness (TH), Total Dissolved Solids, Phosphate, Nitrates, Fluorides, Chloride, Nitrite and Sulphate were analyzed together with heavy metals such as Iron and Copper using standard protocols. Microbial analyzes were also carried out to determine contaminations with respect to total coliform and *Escherichia coli (E.coli)*. The samples taken from retail points and production points showed compliance with respect to physiochemical parameters excluding Nitrite. Excluding WA_3 and WA_7, the others recorded elevated nitrite levels with mean values of WA_1 (3.68mg/l), WA_2 (3.20mg/l), WA_4 (3.80mg/l), WA_5 (4.00mg/l), WA_6 (4.00mg/l), WA_8 (3.65mg/l), WA_9 (3.67mg/l) and WA_{10} (3.34mg/l) at production points. Similar results were recorded also at the retail points where the values recorded are WA_1 (4.00mg/l), WA_2 (4.80mg/l), WA_4 (3.90mg/l), WA_5 (6.10mg/l), WA_6 (6.10mg/l), WA_8 (4.20mg/l), WA_9 (3.80mg/l) and WA_{10} (4.00mg/l). The elevated nitrite levels recorded in the samples pose long term health risk to the public. Samples taken from WA_{10} at both points/sources recorded a mean pH value of 5.20 and 5.90 respectively. These pH values recorded are far below the recommended limit of 6.50-8.50 set by World Health Organization (WHO) and Ghana Standard Authority (GSA). The physiochemical parameters measured did not show any significant differences in the mean values between the production points/sources and retail points/sources of these samples. Samples taken from WA_{10}, WA_7 and WA_5 recorded contamination with total coliform with mean colony count of $1cfu/100ml$, $1cfu/100ml$ and $2cfu/100ml$ respectively. Microbial contaminations recorded in the three brands expose the public to immediate health effect.

ACKNOWLEDGEMENTS

I would like to express my gratitude to the Almighty God for his guidance and protection throughout this study.

I would like also to express my gratitude to my supervisor Dr. M.G. Addo whose scholarly guidance, constructive comments and critical revision of the drafts made it possible for me to complete this thesis. I am also grateful to all the lecturers at the Department of Theoretical and Applied Biology (IDL) – KNUST for assisting me tremendously in the course of this work.

DEDICATION

This work is dedicated to my beloved father, Mr. C.J. Derkye.

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1.0 INTRODUCTION

1.1 BACKGROUND

Drinking water or potable water is water safe enough to be consumed by humans or used with low risk of immediate or long term harm. Accessibility and availability of fresh clean water is key to sustainable development and an essential element in health, food production and poverty reduction. However, safe drinking water remains inaccessible for about 1.1 billion people in the world and the hourly toll from biological contamination of drinking water is 400 deaths of children below age five.Lack of safe drinking water is considered a leading cause of many communicable diseases. Studies have estimated that the provision of clean water and basic sanitation alone would curtail the incidence of diarrhoea by 50%, sleeping sickness by 80% and guinea worm infestation by 100% (Anwar, 1993).

The importance of potable water in the daily lives of urban Ghanaians is worth noting. The safety of the water obtained from sources other than the GWCL cannot be ascertained hence the water is mostly used for other household activities rather than for direct consumption. The most reliable source of drinking water is bottled water which is of good bacteriological quality (ObiriDanso. *et al.,*2003) but it is expensive and thus only within the means of the affluent in the society.

As an alternative, small-scale industries have come up with sachet water popularly known as "Pure Water".This product is 500ml of water in clear nylon square sachets which have been electrically heated and sealed at both ends and widely patronized by both low and middle income earners. The production of sachet water has increased tremendously with over 300 registered producers and 600 unregistered in

Ghana.According to the Food and Drugs Board of Ghana, majority of sachet water are produced under questionable hygienic environmental conditions and they have had cause to impose a ban on some producers.

Earlier investigations conducted on the safety of drinking water in Ghana has shown that bottled water on the Ghanaian market is of good microbiological quality while the quality of some factory bagged sachet and hand-filled/hand-tied polythene-bagged drinking water was noted to be doubtful . This observation was based on studies carried out on water samples to ascertain the presence of heterotrophic bacteria, indicators of faecal contamination (total coliforms, faecal coliforms and enterococci) and for lead, manganese and iron.

Rutz (1996) reported that sachetwater vending machine may not be free of microorganisms, because bacteria like *Straptococcusfaecalis*, have been isolated from sachet water producingmachines.

The proliferation of such packed water therefore raise the question of whether they are well treated and handled vis-à-vis the poor sanitary environment in urban areas in Ghana.Absence of jobs in rural Ghana have increased the number of street children in the urban areas who incidentally find economic refuge in the ice water trade because the starting capital is relatively low and affordable.Unfortunately it is this group that lacks the basic knowledge in hygiene practices.Most of the locally manufactured sachet water find their way into the market without any quality test on them,there is the need for critical examination before they get to the consumer.Laboratory records from Medi-Lab,Techiman shows twenty-five positive cases of typhoid in 2012 and several cases of enterocolitis reported in Holy Family Hospital Techiman, 2012.This could be due to intake of contaminated water or food.

1.2: PROBLEM STATEMENT

The sale and consumption of packaged water continues to grow rapidly in Techiman and other places in Ghana. Drinking water, regardless of its source, is usually subjected to one or more of a variety of treatment processes intended to improve its safety and aesthetic quality. Several studies on the microbial quality of bottled and sachet water have reported violations of international quality standards (Oyedeji *et al*., 2009).

Even if no sources of anthropogenic contamination exist, there is the potential for natural levels of minerals and other chemicals to be harmful to human health (Anawara *et al*., 2002). Chemical parameters of drinking water have the propensity to pose more of a chronic health risk, even though some components like nitrates and nitrites may have an acute impact. Examples of chronic health effects include cancer, liver and kidney damage, disorders of the nervous system, damage to the immune system, and birth defects (Zaslow and Glenda, 1996). Physical parameters affect the aesthetic value of the drinking water and might complicate the removal of microbial pathogens.

The present study aimed to determine the safety of some packaged drinking water sold in the Techiman Municipality. The drinking water quality data would be essential for the implementation of responsible drinking water quality regulations, for characterizing and remediating contaminations and consequently to protect the health of the consumers. This research will also give an insight into the effectiveness of the water treatment processes and hence the extent to which the quality of the packaged water sold in Techiman Municipality met the recommendations of the Ghana Standards Board (1998) and World Health Organisation guidelines (2007).

1.3: MAIN OBJECTIVE:

The aim of this research was therefore to determine the quality of sachet water sold in the Techiman municipality.

1.4: SPECIFIC OBJECTIVES:

The specific objectives included:

1. Take ten different brands out of the twenty for the study.

2. Determine the microbiological quality of the selected sachet water brands.

3. Determine the physiochemical quality of the selected brands.

CHAPTER TWO

LITERATURE REVIEW

2.1 IMPORTANCE OF WATER

Water is one of the most important substances on earth, all living organisms depend on this substance for life. It is a liquid at standard ambient temperature and pressure, but can also exist as a solid or gas. Excluding fat, water composes approximately 70% of the human body by mass. It is a crucial component of metabolic processes and serves as a solvent for many bodily solutes. Water has so many uses, including cooking, washing and recreation. It is also necessary for the healthy growth of farm crops and farm stock and also plays an important role in the manufacture of many products. On earth 96.5% of the planets water is found in seas and oceans, 1.7% in groundwater, 1.7% in glaciers and the ice caps of Antarctica and Greenland (Greenhalg, 2001). It is reported that less than 0.3% of all freshwater is in rivers, lakes and the atmosphere, and an even smaller amount of the Earth's freshwater is contained in biological bodies (Kortatsi, 2006). Some health authorities have suggested that people drink at least eight glasses, of water per day (1.89 litres) (USEPA, 2000) and the British Dietetic Association recommends 1.8 litres (Greenhalg, 2001).Over large parts of the world, humans have inadequate access to potable water and use sources contaminated with disease vectors, pathogens or unacceptable levels of toxins or suspended solids. Reduction of waterborne diseases is a major public health goal in developing countries.

2.2 Overview of Global Access to Drinking Water

Potable water or drinking water, as defined by APHA (1995), is water of sufficiently high quality that can be consumed or used with low risk of immediate or long term

harm. 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. Due to the importance of water, the Millennium Development Goal (MDG) target -7 calls for reducing by 50% the proportion of people without sustainable access to safe drinking water and basic sanitation by the year 2015. Reaching this target needs 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 are both indicators used to monitor progress towards the achievement of the Millennium Development Goals (MDGs) (WHO/UNICEF, 2005).

Safe water accessibility is frequently defined as those with access that comprises the proportion of the population using any piped water, public tap, borehole with a pump, protected well and springs or rainwater as stated by the United Nations Development Program (UNDP, 2006). 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% 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 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

2.4. 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. It has been estimated that lack of clean drinking water and sanitation services leads to water-related diseases globally and b2etween five to ten million deaths occur annually, primarily of small children (Snyder and Merson, 1982). In Techiman, the Ghana Water Company

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Limited (GWCL), which is mandated to provide potable water for the inhabitants of city is unable to supply adequate quantities due to the ever-increasing population and lack of infrastructural expansion.

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 or reliance on sachet water producers

2.5 POLLUTION OF WATER

Water is referred to as polluted when it is impaired by anthropogenic contaminants which results in it being unable to support a human use. Some of these uses of water includes drinking, cooking, washing etc, or undergoes a marked shift in its ability to support its constituent biotic communities, such as fish and plants (http//environment.about.com/environmental events/waterdayqa.htm). Water pollution occurs when pollutants are directly or indirectly discharged into water bodies without adequate treatment to remove harmful compounds. Natural phenomena such as volcanoes, algae blooms, storms, and earthquakes also cause major changes in water quality and the ecological status of water (WHO, 2008). Water pollution affects plants and organisms living in these bodies of water. In almost all cases the effect is damaging not only to individual species and populations, but also to the natural biological communities.

Water pollution is a major global phenomenon that requires continuous evaluation and the needed revision of policies to address the issue at both the local and international levels. It has been reported that water pollution related deaths and disease are the leading cause of mortality worldwide (Pink, 2006), accounting for the

death of more than 14, 000 people daily. Hogan (2010) reported that in India 580 people die daily from water pollution related sickness. It is reported that about 90% of the cities in China suffer from varying degrees of water pollution (EPA, 2009), with about 500 million people lacking access to safe drinking water (Laws, 2000). Developing countries are mostly affected by water pollution however developed nations also have water pollution issues. The USEPA in 2002 reported that, 45% of assessed stream miles, 47% of assessed lake acres and 32% of assessed bays and estuarine square miles are polluted (USEPA, 2002). Surface water and groundwater are interrelated, surface water seeps through the soil and becomes groundwater, alternatively groundwater also feed surface water sources, however, they have often been managed as separate resources (USGS, 1998). Access to Ghana's water resources are not evenly distributed at the spatial level. Only about 39.9 percent of households had access to pipe borne water. Two (2) percent got water supply from tanker services whilst three other sources wells, boreholes, and rivers/streams account for 16 percent each (GSS, 2010). In addition, access to pipe-borne water as a source of drinking water was 67.8 percent in urban areas compared to 14.9 percent in rural areas. At the national level, 42 percent did not have access to good safe drinking water. In Accra, over 91 percent of households had access to pipe-borne water in the year 2000 with 43.6 percent having pipe-borne inside their houses (GSS, 2010).

Water pollution could occur from so many sources; these are grouped into two main categories. These are: Point source pollution and Non-point source pollution. The former refers to contaminants that enter the waterway from a single identifiable source, which may include a pipe or a ditch, discharges from sewage treatment plants, factory, or a city storm drain. The latter refers to diffuse contamination that does not originate from a single discrete source. This is often the cumulative effect of small

amounts of contaminants gathered from a large area. An example being the leaching out of nitrogen compounds from fertilized agricultural lands.

2.5.1 Domestic sources of Water Pollution

A major cause of water contamination is effluent (outflow) from septic tanks and cesspools. Misuse of these systems for disposal of anything other than domestic or sanitary waste can pose a substantial threat to ground water. Residential wastewater systems can be a source of many categories of contaminants including bacteria, viruses and nitrates from human waste and organic compounds.

Injection wells used for domestic wastewater disposal (septic systems, cesspool drainage wells for storm water runoff, groundwater recharge wells) are of particular concern to ground water quality if located close to and up gradient water wells. Improper storing or disposal of household chemicals such as paints, synthetic detergents, solvents, oils, medicines, disinfectants, pool chemicals, pesticides, batteries, gasoline and diesel fuel can lead to ground water contamination. When stored in garages or basements with floor drains, spills and flooding may introduce such contaminants into the ground water because community landfills are not equipped to handle hazardous materials. Similarly, waste dumped or buried in the ground can contaminate the soil and leach into the ground water.

As urban areas grow, there is an increase in rain water runoff caused by the additions of paved surfaces. Some municipalities use storm water drainage wells to dispose off waste, this additional runoff particularly if the area is not served by storm sewer or has a limited sewer system. Storm water drainage that communities use to control water during storm events pose a threat to ground water particularly in kart areas or areas with high water table. Fertilizers, herbicides, insecticides, fungicides and

pesticides applied to the lawn and garden contain hazardous chemicals that can travel through the soil and contaminate the ground water.

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

Water used in the home and entering a septic system or sewer system may contain detergents from dish washing and laundry, organic compounds from garbage, disposal bacteria, nitrates and sulphates from sewage, greases and oils. Cleaning agents, aerosol sprays coolants and solvents which all contain carbon tetrachloride household pesticides. Water percolating through landfills is known as Leachate. From landfills that contain household and other waste may pick up dissolved solids and volatile organic compounds. Lawns with over applied or misapplied fertilizers, herbicides and fungicides might introduce these contaminants tetrachloride and heavy metals such as manganese into the ground (USEPA, 1997).

2.5.2 Natural sources of water contamination.

Water contains some impurities even if it is unaffected by human activities. The types and concentrations of natural impurities depends on the nature of the geological materials through which the ground water moves and the quality of the recharge water.

Ground water moving through the sedimentary rocks and soils may pick up a wide range of compounds such as magnesium, calcium and chlorides. Some aquifers have

high natural concentration of dissolved constituents such as arsenic, boron and selenium. The effect of these natural sources of contamination of water quality depends on the type of contaminants and its concentration. Some of the contaminants that occur naturally are: Aluminium, arsenic, barium, chloride, chromium, coliform bacteria, copper, fluoride, hardness, iron, lead, manganese, mercury, nitrate, selenium, silver, sodium, sulphate and zinc (USEPA, 1997).

2.5.3 Other Sources of water pollution

Water that runs off or flows over the ground after a rainstorm picks up debris, chemicals, soil, yard waste, fertilizer, motor oil and other pollutants. Storm water is carried into local retention (storm water) ponds or directly into local waterways through storm drains that eventually reach water bodies. Sometimes this water is partially treated through a storm water pond. These provide temporary storage of storm water runoff and capture a variety of pollutants that would otherwise work their way downhill to waterways and wetlands. The responsibility for permitting storm water management systems rests with water management authorities. After developers complete construction of permitted systems in residential areas, the permit and the legal responsibility for maintaining these systems are typically passed on to homeowners.

For generations, thousands of acres of farmland have been cultivated throughout Ghana. In many cases, nutrient-rich water from farm fields has drained or been pumped into natural water bodies without treatment, impacting water quality. This overabundance of nutrients encourages algal blooms that deplete oxygen from the water and block sunlight from reaching underwater vegetation, critical to fish and wildlife habitats.

Sediments from soil at construction sites can wash into waterways, which can create problems for aquatic life. Cloudy water caused by suspended matter reduces the amount of sunlight able to reach submersed plants. The settling out of the sand, silt and other matter suspended in the water onto the bottom of the water body destroys submersed grass beds and other bottom-dwelling plants and animals, in addition to impacting drainage and navigation.

Pollution of surface waters is generally categorized as point source or nonpoint source. With point source pollution, the cause of the problem can be traced to a single source — for example, a pipe or culvert discharging wastewater from a factory. Some industrial and sewage treatment plants connect directly to a water body and create point source pollution, but not all pipes create point source pollution. In the past, pollution from industrial and domestic point sources was common. However, stronger regulations, newer technologies and more advanced treatment of wastes have reduced pollution. These sources are regulated by state and local laws.

2.5.3 Microorganisms associated with Water Pollution

Several microorganisms are used to detect the presence of pathogens in water sample, Coliform bacteria are the most commonly used, although not an actual cause of disease. Several microorganisms are found in surface water which are implicated in human health problems, including, *Cryptosporidium parvum, Giardia lamblia, Salmonella, Novovirus* and parasitic worms (Schueler, 2000). High levels of pathogens in water may result from the inadequate treatment of sewage discharges, which is a common feature in developing countries (EPA, 2009), however this may also occur in developed countries, where older cities with aging infrastructure may lead to the leakage of sewage collection systems which can cause sanitary sewer

overflows. Apart from microorganisms, other contaminants of water include organic substances like; detergents, disinfection by-products, food processing waste, fats and grease, insecticides and herbicides, petroleum hydrocarbons, including fuels and lubricants and fuel combustion by-products Acidity caused by industrial discharges (especially sulfur dioxide from power plants), Ammonia from food processing waste, Chemical waste as industrial by-products. Fertilizers containing nutrients--nitrates and phosphates—which are found in storm water runoff from agriculture, as well as commercial and residential use(Burton and Pitt, 2001), Heavy metals from motor vehicles (via urban storm water runoff) (Schueler, 2000) and acid mine drainage, Silt (sediment) in runoff from construction sites, logging, slash and burn practices or land clearing sites.

2.5.3.1 Microbial parameters

Feacal coliforms are mostly used to indicate the faecal contamination of water samples, these mostly determine the presence of *E. coli*, which should be absent in 100 ml of drinking water, this is the Ghana Standards Authority (GSA) standard set. Drinking water should be free of human enteroviruses. Coliforms occur naturally in soil and in the gut of humans and animals. Thus, their presence in water may indicate contamination. *E. coli* and certain species of *Enterobacter aerogenes* are present only in the gut of humans and animals. Their presence therefore indicates definite faecal pollution. The presence of coliform bacteria in well water may be as a result of surface water infiltration or seepage from a septic system (Obiri-Danso *et al.,* 2003).

2.5.3.2 Coliform Bacteria

Total coliform is a term used to refer to a group of bacteria that are commonly found in the environment, in soil or vegetation as well as constitute the normal flora in

mammals including humans. These bacteria mostly do not cause any disease, but their presence in drinking water gives an indication that the water supply may be vulnerable to contamination from more harmful bacteria and other microorganisms. *E. coli* is the only member of the total coliform group of bacteria that is found only in the intestines of mammals, including humans. Therefore the presence of *E. coli* in water indicates recent faecal contamination which may mean the possible presence of disease-causing pathogens, such as bacteria, viruses and parasites. *E. coli 0157:H7* causes hemorrhagic diarrhoea and haemolytic uremic syndrome (HUS) unlike most strains of *E. coli*. Due to this, total coliforms and *E. coli* are used as indicators to measure the degree of pollution and sanitary quality of well water. This is mostly the case because testing for all known pathogens is a complicated and expensive process. In water, coliform bacteria have no taste, smell, or colour. They can only be detected through a laboratory test

2.6 DRINKING WATER QUALITY

The quality of water considered to be wholesome for drinking is basically determined by measuring the level of contaminants present in the water (Ifabiyi, 2008). It is typically assessed under three categories: physical, chemical and microbiological. Physical and chemical parameters include heavy metals, trace organic compounds, total suspended solids (TSS), and turbidity (Krishnan, 2008). Microbiological parameters include Coliform bacteria, *E. coli*, and specific pathogenic species of bacteria such as cholera-causing *Vibrio cholerae*, viruses, and protozoan parasites (Lawson, 2011).

The greatest threat to human health from chemical contamination of water is through the buildup of heavy metals, however some components like, nitrates and arsenic can

also cause immediate health effect. Physical parameters affect the aesthetics and taste of the drinking water and may make the removal of microbial pathogens difficult (Oluyemi, 2010).

Coliform bacteria presence in water samples give an indication of faecal contamination of the water sources (example *E. coli*). Other contaminants include protozoan oocysts like *Cryptosporidium sp, Giardia lamblia* and enteric viruses (EPA, 2010). These microbial pathogens are the most important due to their immediate effect on health.

Globally the most common contaminant of raw water sources is human sewage and in particular faecal pathogens. The Center for Disease Control and Prevention reported in 2006 that waterborne diseases were estimated to cause over 1.8 million deaths every year while about 1.1 billion people lack access to proper drinking water (CDC, 2006). It is clear that people in the developing world need to have access to good quality water in sufficient quantity, water purification technology and availability and distribution systems for water. In many parts of the world the only sources of water are from small streams often directly contaminated by sewage.

2.6.1 WATER QUALITY ASSESSMENT PARAMETERS

The Ghana Standards Authority set standards for drinking water which is used in determining how safe water is for human use in Ghana, these standards indicate the required physical, chemical, microbial and radiological properties of drinking water. These standards are adapted from the World Health Organizations Guidelines for Drinking Water Quality, Second Edition, Volume 1, 1993, but also incorporate national standards that are specific to the country's environment.

2.6.2 Physicochemical parameters

Water must be assessed before it is used for drinking, domestic, agricultural or industrial purposes. This is mostly done with different physicochemical parameters, which mostly depend on the purpose of the water and the extent to which the quality and purity is required (Umar *et al*., 2003). Water has different types of physical, chemical and biological impurities. These require different tests to determine the level of these contaminants in the water. To obtain water of good quality, it should be tested for trace metals, heavy metals, organic materials and biological contaminants. For water to be considered as good for drinking then it should pass all these tests and it should also contain required amount of mineral level (Umar, 2006).

2.6.3. Temperature

In any system the water temperature controls the rate of all reactions, this affect the growth of fish and other aquatic organisms. It also has a role in determining the survival of microorganisms in the water body (Zuane, 1990). It is reported that drinking water should have a maximum temperature of 15 degrees celcius (http://www.env.gov.bc.ca).

2.6.4 pH

The corrosive nature of water can be determined by the pH, the lower the pH the higher the corrosive nature of water. This is positively correlated with electrical conductivity and alkalinity (Gulta, 2009). The reduced rate of photosynthesis and the assimilation of carbon dioxide and bicarbonates ultimately result in the increase in pH.

Higher pH values observed suggests that carbon dioxide, carbonate-bicarbonate equilibrium is affected more due to change in physico-chemical condition (Karanth

1987). The usual pH for fresh water aquatic system is 6 to 9 with most water record around this pH, is an indicator of existence of biological life as most of them thrive in a quite narrow and critical pH range. However, (WHO, 1984) stipulated that drinking water should have pH range of 6.5 to 8.5. Darko-Mantey*et al*., (2005), did a study on drinking water from different sources and observed a pH range of 6.1 to 7.2. pH is related in several different ways to almost every other water quality parameter, as aqueous chemical equilibria invariably involve hydrogen ions, H^+ (WHO,1984)

2.6.5 Electrical conductivity

This shows correlation with several parameters including temperature, pH value, alkalinity , total hardness , calcium , total solids, total dissolved solids , chemical oxygen demand , chloride and iron concentration of water. The quality of drinking water can be determined by controlling the conductivity of water and this may also play a major role in water management (Kumar *et al*., 2010). It is measured with the help of EC meter which measures the resistance offered by the water between two platinized electrodes. The instrument is standardized with known values of conductance observed with standard KCl solution. The electrical conductivity of water increases by 2-3% for an increase of 1 degree Celsius of water temperature. Many EC meters nowadays automatically standardize the readings to $25^{o}C$. Human activities also influence conductivity. Acid mine drainage can add iron, sulphate, copper, cadmium and other ions if minerals containing them are exposed to air and water. Sewage and farm runoff can raise conductivity due to the presence of nitrate and phosphate. Runoff roads can also carry salt and other materials that contribute ions to water. WHO (1984) recommended 1000μS/cm maximum conductivity limit for drinking water.

2.6.6 Alkalinity

This acts as a stabilizer for pH, it primarily consists of carbonate (CO_3^{-2}) and bicarbonate (HCO_{-3}). Alkalinity, pH and hardness affect the toxicity of many substances in the water. This is determined by HCI titration in the presence of phenolphthalein and methyl orange indicators. Alkalinity in water mainly comes from the presence of hydroxyl and carbonate ions (Ashbolt *et al*., 2001).

2.6.7 Dissolved Oxygen (DO)

This is one of the most important parameters in determining water quality. It gives direct and indirect information on the bacterial activity, photosynthesis, availability of nutrients, stratification etc (Premlata Vikal, 2009). Increase in temperature and increase in microbial activity result in a decrease in DO (Kataria, 1996). Intense sunlight seem to accelerate photosynthesis phytoplankton, utilizing CO_2 and giving off oxygen, this accounts for the higher quantities of O_2 recorded during higher temperatures (Krishnamurthy, 1990). DO in water sample is measure tritrimetrically by Winkler's method after 5 days incubating at 293K. The difference in the initial and final DO gives an indication of the amount of oxygen consumed by the bacteria during this period, this is mostly done using special DO bottles that seal the inside environment from atmospheric oxygen.

2.6.8 Total Dissolved Solids

This correlate well to the total mineral content of the water, this is primarily salts, carbonates and metals. Organic compounds may also be considered as dissolved solids. High TDS indicates a high volume contamination and a further investigation may be recommended. The TDS in water consist of organic salts and dissolved materials. In natural waters, salts are chemical compounds comprise of anions such as

carbonates, chlorides, sulphates and nitrates (primarily in ground water), and cations such as potassium, magnesium, calcium and sodium. In ambient conditions, these compounds are present in portions that create a balanced solution (http://www.duluthstreams.org). According to WHO (1984), there has not been any deleterious physiological reactions occurring in persons consuming drinking water that have TDS values in excess of 1000mg/l. WHO, however, recommends the low level of the latter as a guideline value for TDS.

2.6.9 Sulphate

This is measured by nephelometric method in which the concentration of turbidity is measured against known concentration of synthetically prepared sulphate solution. The turbidity is produced by barium chloride as a result of barium sulphate and a mixture of organic substance and sodium chloride is used to prevent the settling of turbidity (Ashbolt *et al*., 2001). Atmospheric sulphur dioxide (SO_2), formed by the combustion of fossil fuels and by the metallurgical roasting process, may also contribute to the sulphate content of surface waters. It has frequently been observed that the levels of sulphate in surface water correlate with the levels of sulphur dioxide in emissions from anthropogenic sources.

Hydrogen sulphide gas also occurs naturally in some groundwater. It is formed from decomposing underground deposits of organic matter such as decaying plant material. It is found in deep or shallow wells and also can enter surface water through springs, although it quickly escapes to the atmosphere. Hydrogen sulphide often is present in wells drilled in shale or sandstone, or near coal or peat deposits or oil fields.

Sulphates have a detoxifying effect on the liver and stimulate the function of the gall bladder and thus the digestive function as well. USEPA as well as WHO set the Maximum contaminant level of sulphate in drinking water at 250 mg/L.

2.6.10 Nitrates

Nitrate ions are not absorbed by soil and therefore move with infiltrative water. Water is mostly contaminated with nitrates from agricultural fertilization, municipal and industrial waste can also contribute a significant amount of nitrates to water (Ashbolt *et al*., 2001). Drinking water nitrate levels are extremely important with infants, because they have a high intake of water with respect to body weight. Nitrates in the infant are converted by the body to nitrites that oxidize blood haemoglobin to methaemoglobin. These altered blood cells can no longer carry oxygen resulting in brain damage or suffocation, therefore nitrite levels exceeding 1.0 mg/L should not be fed to infants. Epidemiological studies show a correlation between high nitrate levels and gastric and stomach cancers in humans (WHO, 1993).

2.6.11 Phosphates

Phosphate enters water through several channels, which may include, decomposition of rocks and minerals, storm water runoff, agricultural runoff, erosion and sedimentation and even directly from animals. Waste water from both domestic and industrial settings is another major means by which phosphate can enter water. High concentration of phosphate in water bodies is an indication of pollution and largely responsible for eutrophication. Toxicity of phosphate occurs at very high concentrations, which could result in digestive problems, therefore the WHO has set the maximum concentration of this substance in drinking water to 0.3mg/L.

2.6.12 Chloride

Water containing chloride could be from natural sources or as a result of pollution from various sources. Chlorides are generally distributed in nature as salts such as sodium (NaCl), potassium (KCl) and calcium ($CaCl_2$) (Department of National Health and Welfare (Canada), 1992). Concentration of chloride exceeding 250mg/L can result in detectable taste in water. The electrical conductivity of water and its corrosity increase as a result of the presence of chloride in water.

2.6.13 Flouride

This does not occur in nature in its elemental state due to its high reactivity, but traces are present in many water bodies. But higher concentrations are associated with underground sources. A total concentration of 1.3 mg/L has been reported in seawater, but in areas that contain a lot of fluoride containing minerals, well water could have as high as 10mg/L. Fluorides may also enter water bodies as a result of industrial discharge (Ashbolt *et al*., 2001).

Many studies have looked at the possible effect of long term exposure to fluoride on the health of humans, from which it has been established that the primary effect of fluoride is on skeletal tissues such as bones and teeth, however low concentrations provide protection against dental caries. The minimum concentration of fluoride in drinking-water required to produce it is approximately 0.5 mg/litre. Skeletal tissues as mentioned earlier can be seriously affected by fluoride resulting in skeletal flourosis which is generally seen when the drinking water contains 3-6 mg of fluoride per litre, levels exceeding 10mg/L results in crippling skeletal flourosis.

2.6.14 Potassium

This is an essential element for humans and is hardly found in water in concentrations that would have adverse health effect on the body. Potassium occurs widely in the environment and is mostly found in water as a result of the use of potassium permanganate as an oxidant in water treatment. In some countries, potassium chloride is being used in ion exchange for household water softening in place of, or mixed with, sodium chloride, so potassium ions would exchange with calcium and magnesium ions (WHO, 2004). The high solubility of potassium and its wide use especially in water treatment can result in high exposure. This element in addition to sodium are necessary for the maintenance of normal osmotic pressure in cells, it is also a cofactor for many enzymes and it is important in the secretion of insulin, creatine phosphorylation, carbohydrate metabolism and protein synthesis. Case-studies of toxicity resulting from high doses of salt substitutes have described chest tightness, nausea and vomiting, diarrhoea, hyperkalaemia, shortness of breath and heart failure (WHO, 2004). WHO set maximum contaminant level at 30mg/l.

2.7 TREATMENT OF WATER

Before water could be used it requires some extent of treatment, even water from sources that are perceived to be clean such as wells and springs. The extent of treatment however depends on the source of the water. There are several technologies used in the treatment of water, which include both community-scale and household-scale point-of-use designs (www.who.int/water_sanitation_health/monitoring/jmp04 .pdf). It is also possible to kill water borne pathogens through boiling, this is mostly done in the absence of conventional treatment systems or when these treatment systems have been compromised (WHO, 2004). However this method (boiling) is not reliable when it comes to killing encysted parasites such as Cryptosporidium or the

bacterium Clostridium. Other techniques, such as filtration, chemical disinfection, and exposure to ultraviolet radiation (including solar UV) have been demonstrated to significantly reduce levels of water-borne disease among users in low-income countries (Clasen *et al*., 2007), but these suffer from the same problems as boiling methods.

Water purification refers to the process of removing contaminants from untreated water to produce drinking water of good quality for its users. Some substances removed during water treatment include solids, bacteria, algae, viruses fungi, minerals such as iron, manganese and sulfur, and other chemical pollutants such as fertilisers. Measures taken to ensure water quality not only relate to the treatment of the water, but to its conveyance and distribution after treatment as well. It is therefore common practice to have residual disinfectants in the treated water in order to kill any bacteriological contamination during distribution.

Treatment of water is mostly a combination of various processes, pre-chlorination, aeration, coagulation, sedimentation, filtration, desalination and disinfection are used in treating water for municipal consumption. There is no unique solution (selection of processes) for any type of water (Diersing-Nancy, 2009). Also, it is difficult to standardize the solution in the form of processes for water from different sources. Treatability studies for each source of water in different seasons need to be carried out to arrive at the most appropriate processes. As a result of this technologies for potable water treatment are well developed, and generalised designs are available that are used by many water utilities (public or private). In addition, a number of private companies provide patented technological solutions (Diersing-Nancy, 2009).

2.8: SUPPLY OF DRINKING WATER

The supply of drinking water is the provision of potable water by publicly owned utility companies, commercial organisations, community endeavours and individuals, usually distributed through a system of pumps and pipes (IDLO, 2006). Most of the water utilities supply water within a single city, a town or municipality. However in many countries, utility companies supply water to larger areas such as a whole province, region or in some cases the whole country as is the case in Ghana and many other West African countries and in some South American countries, Tunisia, Jordan and Urugauy. In England and Wales, water supply and sewerage is supplied almost entirely through ten regional companies (IDLO, 2006). In rural areas, where about half the world population lives, water services are often not provided by utilities, but by community-based organizations which usually cover one or sometimes several villages.

2.8.1: Supply of Drinking Water in Ghana

The genesis of water supply in Ghana started with the construction of a supply system in Cape Coast in the year 1928, and was under the supervision of the Water Supply Division of the Public Works Department (PWD). This was the body responsible for the supply of water in rural and urban Ghana, however after independence this division was separated from the PWD and placed under the Ministry of Works and Housing which subsequently led to the establishment of the Ghana Water and Sewage Corporation (GWSC) in 1965. A legal public utility responsible for the provision of urban and rural water supply for public, domestic, and industrial purposes as well as the establishment, operation, and control of sewerage systems was therefore instituted.

Since the establishment of water supply in Ghana it has been faced with several challenges, including very limited access to sanitation, intermittent supply, high water losses and low water pressure. However the sector has undergone several reformations since 1994, some of which includes the creation of an autonomous regulatory agency (The Public Utility Regulation Commission), the introduction of private sector participation, decentralization of the supply of water in rural areas to 138 districts and increased community participation in the management of rural water supply systems. In 2006 an international company, Aqua Vitens Rand, managed urban water supply in Ghana under a five year management contract which was not renewed due to its inability to meet all objectives of the contract agreement. There were a lot of reforms also aimed at increasing cost recovery and the modernization of urban water supplier, Ghana Water Company Ltd (GWCL), formed from the Ghana Water and Sewage Corporation (Water Aid, 2008). Another problem which partly arose from the recent reforms is the existence of a multitude of institutions with overlapping responsibilities. The National Water Policy (NWP), launched at the beginning of 2008, seeks to introduce a comprehensive sector policy (GWRC, 2008).

In Accra there are varying degrees of access to water supply, with only one quarter of the entire city population receiving continuous supply, 30% receive supply for 12 hours each day for five days in a week, with another 35% supplied for two days a week. The remaining 10% who mainly live on the outskirts of the capital are completely without access to piped water (Water Aid, 2008), however in 2010, 86% of the entire population of Ghana had access to water (WHO/UNICEF, 2012). Other reports give a much worse situation, stating that some communities in the Accra-Tema area being served only once a week, or once in a fortnight of even once in a month (Doe, 2007).

2.9 SACHET WATER IN GHANA

Due to the unreliability of the water supply system in Ghana, sachet water was introduced to provide affordable and instant drinking water to the general public, this has seen a tremendous increase due to the crisis in the water supply system in the country. The sachet is usually bagged in small polythene bags usually 500ml, this product has found its way into almost every home in the country. There have been reports that suggest the use of this product in hospitals, even in theatres and delivery rooms. The production of sachet water is carried out by both small and large scale industries that pack and machine-seal sachet water, this bag of water is mostly referred to as "pure water". According to the Stockholm Environment Institute (1993), "ice-water" vendors get their local name because most of them add blocks of ice to water sachets contained in ice-boxes or pots to cool the water. However, to majority, "ice-water" simply means hand-tied sachet water weather it is coole2d or not. Sachets are produced by both large corporations and small family businesses often regarded as "cottage industries." Corporate producers are few in number and generally located in the large cities. Some of the large scale producers in Ghana, Everpure, IceCool, Mobile Water, Standard Water, Voltic and Special Ice Water, however the number of the small scale industries producing sachet water are unknown. Governmental agencies tasked with managing the industry are not able to account for all the small scale producers because there are several unregistered producers in business, however they have been reported to be around 3,000 and on the rise each day. The proliferation of these producers is as a result of strong seasonal demand, intermittent water supply and low barriers to market entry, most of these small scale producers are typically family enterprises drawn to the industry because it

is a relatively simple business to run, does not require extensive education, and has low initial investment.

2.10 SACHET WATER PRODUCTION

The production of sachet water is a relatively simple process, most of these producers are located within areas where there is the supply of treated water from the Ghana Water Company Limited (GWCL), therefore a water pump draws directly from a piped connection, in some areas where there is no water supply these producers have a borehole or well from which they draw their water. The water is then passed through a filtration media and into the sachet machine which fills a fixed volume (typically 500 mL) of a plastic roll, then heat-seals and slices the edge to create the individual sachet. These sachets are then packed into bags of thirty each.

The machines used in the production of the sachet water are mostly manufactured in China and marketed under several brand names with the most common being the Koyo Machine. The filtration of the water is mostly done with a separate filtration media which is usually fixed to a wall, this contains a combination of carbon and sand filters of varying pore sizes for trapping different particles and organisms. These machines sometimes contain ultraviolet filters for killing remaining bacteria and viruses, some of the producers who deliver straight to the market usually cool the water before distribution.

2.11: SACHET WATER QUALITY

Due to the high demand for sachet water and the lack of serious supervision and regulation most of the sachet water produce does not meet the required standard. In the developed world vended water technology has evolved but in many developing nations sachet is the common technology available.

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There has been several studies on the quality of sachet water in Ghana, in 2006 Dodoo*et al.,* studied the quality of 29 brands of sachet water exposed to different temperature conditions in the Cape Coast Metropolis . In this study, 45% were reported to be contaminated with total coliform bacteria, with colony forming units (CFU) ranging from 0 cfu/100ml to 98 million cfu/100ml, with three out of seven brands reporting positive for E. coli. This study indicated that sachet water quality in Ghana was poor, however in comparing the quality of sachet water with other water products, sachet water is of a higher quality than hand –filled hand –tied water which was dominating in Ghana before the introduction of sachet water this was reported in a study by Obiri-Danso *et al.,* (2003). Most of the water used in the production of sachet water in Ghana is either from the GWCL or from underground water sources, these underground water has been proven from several studies to be microbially contaminated, as was reported by Obiri-Danso *et al.,* (2008).

Recent research on sachet water has primarily focused on sub-standard quality and potential disease transmission, with some elaboration on health impact. Despite scientific interest in microbiological quality of sachet water that dates back to at least the mid-1990s there is a striking paucity of research on the topic. Most of this literature also appears in African journals that are not linked to major databases like Pub -Med, which slows the dissemination of findings and subsequent rousing of interest in these issues, particularly with international organizations that may have the resources to investigate further.

CHAPTER THREE

METHODOLOGY

3.1:STUDYAREA

3.1.1 MAP OF THE STUDY AREA

Figure 1: Map of the study area

3.1.2: Location

The Municipality lies between longitudes 10 49'East and 20 30' West and latitudes 80 00' north and 70 35' South. The Municipality shares common boundaries with Wenchi Municipality to the North and West, Kintampo south District to the North-East, Nkoranza South District to the South-East and Offinso-North District (in the Ashanti Region) to the South. Total land area is 669.7 square kilometer.

The Municipality has a high population with an estimated of 206,856(Ghana Statistical Service, 2010) and also with population growth rate of 3.84% with a population density of 343 people per square kilometer (Ghana Statistical Service, 2010)

3.1.3: Climate

The Techiman Municipality experience both semi-equatorial and tropical conventional or savanna climates, characterized by moderate to heavy rainfall annually.

The major rains start from April to July and the minor from September to October, then the only dry season which is highly pronounced in the savanna zone, starts in November and lasts until March.

The highest rainfall of over 1650mm is recorded in the south-west and declines northwards to about 1250mm in the North West Guinea-savanna zone around Offuman area. It has annual average temperature of 28 ^{oC} and a relative humidity of 75-80% in the rainy season and 70-72% for the rest of the year.

3.2: SAMPLING

The brands of sachet water sold were purposively selected from February to April, 2013. Triplicate samples were taken from these selected brands at the source of production and also at the retail point within the same day. A total number of sixty (60) samples were taken for the study. These were quickly placed on ice chest and transported to the laboratory for analysis.

3.3: LABORATORY ANALYSIS.

Physicochemical parameters were analyzed using the APHA, 1995 procedures. Bacterial contamination was determined using the MPN method as reported by APHA, 1995

3.3.1: STATISTICAL ANALYSIS

The Data collected were analyzed using the Microsoft Office Excel.

3.3.2: pH determination

The pH meter was calibrated with 4.0, 7.0 and 10.0 pH buffers and ensured that a plot of mV verses pH followed the nerstian relation. A 100ml aliquot of each sample was measured into a beaker and the pH determined using a pH meter. This was done at the time of the analysis in the laboratory.

3.3.3: Conductivity determination

The conductivity meter was standardized with 0.01N KCL solution. The conductivity of this solution was found to be 1413 μs/cm at 25 ℃ with a cell constant of 1. 100ml sample of water was measured into a beaker and its conductivity determined with the WTW conductivity meter within two hours of sampling. The determinations were made after refrigerated samples had been allowed to attain room temperature.

3.3.4: Total dissolved solids (TDS) determination

A 50ml well-mixed sample was measured into a beaker. The WTW TDS/ Conductivity meter probe was immersed in the sample and its conductivity recorded.

3.3.5: Temperature determination

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

3.3.6: 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 this 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.

3.3.7: Colour determination

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

3.3.8: 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 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 samples for all the analysis.

3.3.9: Turbidity determination

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

3.3.10: Total Metal determination using Atomic Absorption Spectrophotometer (AAS).

The concentrations in mg/L of two metals were determined in all the samples namely, Cu, and Fe with the Atomic Absorption Spectrophotometer. The flame used for the analysis was air-acetylene mixture. A 100ml stock solution of multi –element solution was obtained from the laboratory of the Ghana Water Company, Kumasi. 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 4.0

Cu: 3.7mg, and 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 and Cu at 324.8.

3.3.11: Digestion of samples for 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.

3.3.12: Total Hardness Determination

A 200ml sample was measured into a conical flask. To this was added 0.4ml portion of ammonium chloride buffer solution and was then followed by the addition of 12mg erichome black T indicator crystal. The resulting solution was titrated with 0.01M

EDTA solution with continuous stirring until the end point was reached. The end point is when the last reddish tinge disappears.

Calculations: (total hardness) mg/L $CaCO_3$ = AXBX1000

I ml sample

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

3.3.13: Alkalinity Determination

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

The following equation was used in the calculation

Alkalinity mg $(CaCO_3)$/L=AXNX50, 000

1ml sample

Where A=ml of acid used.

N= Normality of standard acid used

3.3.14: Chloride Determination by argentometeric titration.

An aliquot of 50ml of sample was measured into a conical flask. The pH was then adjusted to a range of 7-10 with H_2SO_4 for high pH samples and NaOH for low pH samples. Two drops of K_2CrO_4 indicator was added. Standard $AgNO_3$ solution of 0.01M was titrated against the resulting mixture above to a pink yellow end point. Blank titration with only the reagents and no water sample was also performed

Chloride (mg chloride per litre) = XxNx1000x35.5

1ml of sample

X=end point volume.

N=Normality of $AgNO_3$.

3.3.15: Microbial analysis

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

3.3.15.1: 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. One milliliter aliquots from each of the dilutions were inoculated into 5ml of MacConkey Broth and incubated at 44^0C 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. Counts per 100ml were calculated from MPN tables.

3.3.15.2: 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 44^0C 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.

CHAPTER FOUR

RESULTS

4.1 Mean values of measured parameters at the point of production and retail

The mean pH of the water samples taken was generally higher at the point of retail (6.96) than the point of production (6.89) (Figure 1). Similar results were obtained for turbidity (1.2 NTU and 1.19 NTU respectively), temperature (24.0 °C and 23.5 °C), total dissolved solids (110 mg/L and 109 mg/L), chloride (0.45 mg/L and 0.38 mg/L), nitrate (15.90 mg/L and 14.50 mg/L) and nitrite (3.90 mg/L and 3.85 mg/L). However the reverse was observed for the other physic-chemical parameters. Microbial contamination of the water as measured gave only three positive samples for total coliform, these were all at the point of production. The comparison of these measured parameters between the points of production (1.60 mg/L for total suspended solids, 7.50 for alkalinity, 5.80 PCU for colour, 12μs/cm for conductivity, 0.18 mg/L for Flouride, 0.03mg/L for Iron, 0.03 mg/L for copper, 9.00 mg/L for Sulphate and 0.95 mg/L phosphate) and retail (1.40 mg/L for total suspended solids, 6.90 for alkalinity, 5.50 PCU for colour, 5.50 μs/cm for conductivity, 0.16 mg/L for Flouride, 0.01 mg/L for Iron, 0.01 mg/L for copper, 8.3 mg/L for Sulphate and 2.1 mg/L phosphate).

4.2 Quality of the selected brands of water the point of production

In all ten brands of sachet water was sampled over the period of the study starting from February to April, 2013.These wereWA$_1$, WA$_2$, WA$_3$, WA$_4$, WA$_5$, WA$_6$, WA$_7$, WA$_8$, WA$_9$ and WA$_{10}$. The lowest mean pH value (5.20) was recorded at WA$_{10}$this value is far below the recommended limit of 6.5-8.5 set out by the Ghana Standard Authority and World Health Organization. The highest (7.53) recorded at WA$_1$. The mean temperature recorded across the various production points were all within the

range of 25.1°c to 25.35°c. However, electrical conductivity values recorded a wider range of values, the lowest value of 7.85us/cm was recorded WA_2 and the highest (27.5 us/cm) recorded at WA_5. There was no significant difference (p= 0.34)between the various brands of water for temperature and electrical conductivity. However there was significant difference (p=0.03)for the total dissolved solids values obtained, where the lowest(10.13mg/l) was recorded at WA_2 and the highest (365mg/l) at WA_5. Total suspended solids, total hardness, alkalinity, colour and turbidity all did not give any significant difference between the various brands of water samples. The table below (Table 1) gives a comparative description of the values recorded for all these parameters.

Table 1: Mean concentration of physical parameters of the ten brands of sachet water (production source)

Code	pH	TDS (mg/l)	TSS (mg/l)	Colour (TCU)	Cond. (µs/cm)	Temp. (°C)	Turbidity (NTU)	Alkalinity	Total Hardness
WA_1	7.53	22.50	1.30	9.60	17.50	25.30	2.00	37.66	8.00
WA_2	7.20	10.13	1.00	2.00	7.85	25.20	1.40	23.00	8.66
WA_3	6.70	20.90	1.30	2.00	16.50	25.10	1.10	39.66	8.00
WA_4	7.10	108.00	1.30	2.60	8.70	25.00	1.00	29.33	9.00
WA_5	6.60	366.50	2.30	5.60	29.00	25.20	1.60	22.33	6.00
WA_6	7.30	26.90	3.60	6.00	21.20	25.10	1.00	17.66	7.33
WA_7	6.80	345.50	1.60	3.00	27.40	25.20	1.00	35.00	5.33
WA_8	7.20	10.60	1.30	6.30	8.40	25.10	2.10	18.66	9.00
WA_9	6.90	78.20	1.00	5.00	18.90	25.20	1.00	21.33	5.00
WA_{10}	5.90	13.90	1.30	4.60	11.20	25.10	1.00	26.33	6.33

The highest fluoride concentration (0.24 mg/L) was recorded at WA_6, therefore giving an indication that all measured fluoride levels were within the recommended limits of 1.50 mg/L. same could be said for the rest of the chemical parameters where none exceeded the recommended standards. There was no significant difference between the samples taken for any of the chemical parameters measured. The table below (Table 2) gives the comparison between the brands of water.

Table 2: Mean concentration of chemical parameters of the ten different brands of sachet water (production source)

Code	Cl^-mg/L	F^- mg/L	NO_3^- mg/L	NO_2^- mg/L	SO_4^- mg/L	PO_4^- mg/L	Fe mg/L	Cu mg/L
WA_1	0.47	0.13	12.00	3.68	11.33	1.10	0.012	0.001
WA_2	0.40	0.16	7.68	3.20	8.66	0.85	0.002	0.001
WA_3	0.47	0.18	11.00	0.67	9.00	0.98	0.003	0.002
WA_4	0.47	0.15	15.00	3.80	8.66	0.77	0.001	0.001
WA_5	0.38	0.15	27.00	4.00	8.00	0.64	0.002	0.001
WA_6	0.29	0.24	26.70	4.00	8.65	0.87	0.001	0.001
WA_7	0.52	0.19	15.36	1.34	8.66	0.77	0.001	0.001
WA_8	0.28	0.16	7.71	3.65	8.33	0.82	0.002	0.002
WA_9	0.28	0.15	10.35	3.67	8.33	0.75	0.001	0.002
WA_{10}	0.20	0.16	12.36	3.34	8.00	0.79	0.001	0.002

4.3 Quality of the selected brands of sachet water, the point of retail

Just as was the case at the point of production, the lowest mean pH value (5.9) was recorded at WA_{10} and the highest again at WA_1, there was no significant difference between the various samples. Mean temperature and electrical conductivity values all did not record any significant difference (p=0.56 and 0.34 respectively) with close range of values for temperature (25.1 ^{o}c. to 25.45^{o}c) and for electrical conductivity, between 6.4 us/cm (WA_9 Water) and 28.8 us/cm (WA_5 water). Total dissolved solids again had a significant difference (p=0.02) between the values for the various brands, highest value of 365 mg/L was recorded at WA_5 and the lowest (10.1 mg/L) at WA_2. The rest of the other parameters did not record any significant difference with mean values. Shown in the table below (Table 3) are comparisons of the mean values recorded for the various brands of water.

Table 3: Mean concentration of physical parameters of the ten different brands of sachet water (retail source)

Code	pH	TDS (mg/l)	TSS (mg/l)	Colour (TCU)	Cond. (µs/cm)	Temp. (°C)	Turbidity (NTU)	Alkalinity	Total Hardness
WA_1	7.50	22.70	1.00	6.33	17.40	25.30	2.00	38.00	8.00
WA_2	7.20	10.10	1.33	2.00	7.86	25.20	1.37	23.00	9.00
WA_3	6.70	21.00	1.00	2.00	16.56	25.20	1.06	39.66	8.00
WA_4	7.10	108.00	1.33	2.66	8.70	25.10	1.01	30.00	6.66
WA_5	6.80	365.66	1.66	5.66	29.06	25.20	1.57	22.66	6.00
WA_6	7.40	26.96	3.66	5.66	21.23	25.10	1.01	17.66	6.66
WA_7	6.80	341.53	1.66	3.33	27.40	25.10	1.04	35.00	4.33
WA_8	7.10	10.80	1.33	5.66	8.33	25.10	2.07	19.33	9.00
WA_9	6.90	78.20	0.66	5.00	6.33	25.20	1.01	21.33	5.00
WA_{10}	5.20	140.00	1.33	5.00	11.20	25.10	1.01	26.66	6.66

Table 4: Mean concentration of chemical parameters of the ten different brands of sachet water (retail source)

Code	Cl^- mg/L	F^- mg/L	NO_3^- mg/L	NO_2^- mg/L	SO_4^- mg/L	PO_4^- mg/L	Fe mg/L	Cu mg/L
WA_1	0.46	0.12	8.02	4.00	9.60	1.10	0.001	0.001
WA_2	0.38	0.17	6.01	4.80	8.70	0.80	0.001	0.001
WA_3	0.47	0.20	7.69	2.00	7.90	0.90	0.013	0.015
WA_4	0.29	0.15	10.02	3.90	8.70	0.70	0.011	0.001
WA_5	0.56	0.15	20.02	6.10	8.60	0.70	0.001	0.001
WA_6	0.56	0.20	19.02	6.10	8.90	0.80	0.001	0.001
WA_7	0.33	0.19	12.36	0.29	9.50	0.70	0.001	0.001
WA_8	0.38	0.16	6.04	4.20	8.80	1.00	0.001	0.001
WA_9	0.47	0.19	5.02	3.80	9.50	0.70	0.001	0.001
WA_{10}	0.38	0.15	12.70	4.00	9.20	0.70	0.001	0.001

Flouride concentrations were comparatively higher (0.20 mg/L) with WA_6 and WA_3 water brands. WA_3 again recorded the highest mean concentrations for iron and copper (0.013 mg/L and 0.015mg/L respectively and WA_1 recording the highest concentration of phosphate (1.1 mg/L). It is worth noting that all these parameters were within the recommended limits and there is no significance in the variation of their mean concentrations. Table 4 above gives a representation of these recorded mean concentrations.

4.4 Microbial quality of the water samples

Only three samples taken from WA_{10}, WA_7 and WA_5 at the points of production recorded any form of microbial contamination. These were contaminated with total coliforms, recording 1cfu/100ml, 1 cfu/100ml and 2cfu/100ml respectively (Table 1).

Table 5: Mean Total coliform concentration in the Water samples

SAMPLE CODE	COLIFORM LOADS (cfu/100ml)
WA_1	ND
WA_2	ND
WA_3	ND
WA_4	ND
WA_5	2
WA_6	ND
WA_7	1
WA_8	ND
WA_9	ND
WA_{10}	1

CHAPTER FIVE

DISCUSSION

5.1 PHYSICOCHEMICAL QUALITY OF SACHET WATER

The physical and chemical quality of the water analyzed from both production and retail points gave similar results indicating that there was no contamination of these results within the supply chain. pH values below 6.5 makes water too acidic for human consumption, water with such low values could cause serious health complications due to acidosis and water with higher pH above 8.5 could also lead to serious homeostatic in-balance due to alkalosis. Based on this the Ghana Standard Authority (GSA) and World Health Organization (WHO) sets a pH standard of 6.5-8.5 for drinking water. Mean pH values from all production and retail points were all within this set standard. However comparing individual water samples at both the production and retail points, WA_{10} water had a pH below the recommended standard (5.2 and 5.9 respectively). This gives a compliance percentage of 87.5%. This compliance percentage is above the percentage recorded by Ackah *et al.,* (2012) from studies conducted on water samples from Accra, Odumase-Krobo and Nsawam. In that study they reported a compliance of 78% for pH. Therefore the sachet water sold in the study area was unlikely to cause any health problems relating to pH such as acidosis and alkalosis (Asamoah and Amorin, 2011). Increase, observed in pH, could be attributed to the production of basic metabolic waste products by increasing bacterial population. In their review, Prescott *et al*. (1999) stated that microorganisms frequently change the pH of their own habitat by producing acidic or basic metabolic waste products. All other physical parameters determined by this study were found to be within the recommended standards by the GSA, these parameters seem not to be

affected by conditions that pertain within the chain of transport to the retail points, however there some variations in their levels at the various points (production and retail points). For example, total suspended solids (1.60 mg/L), alkalinity (7.50), colour (5.80 PCU), conductivity (12 µs/cm) and total hardness (29 mg/L) all recorded higher values at the point of production than at the retail points (1.40 mg/L, 6.90, 5.50 PCU, 10µs/cm and 20 mg/L respectively). It is however worth noting that these variations in physical parameters from the production point to the retail points were not significant (p=0.23). This high concentration of physical parameters at the point of production but lower at the retail points could be attributed to the possibility that the batch of samples taken at the production may be different from those taken at the retail points, hence the difference in recorded values. Turbidity is caused by suspended particles or colloidal matter that obstructs light transmission through the water. Turbidity does not have a health based guideline, but it is recommended that it should be ideally below 5.0 NTU. Conductivity is an indication of total dissolved solids (TDS), both organic and inorganic found in the water. Hardness gives palatability to water. It has been suggested that moderately hard water containing sufficient calcium is essential for normal growth and health. However, high values of hardness arising from elevated levels of magnesium sulphate are undesirable (Dodoo *et al.*, 2006).

The palatability of water with total dissolved solids (TDS) level of less than about 600mg/l is generally considered to be good, whereas drinking water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000mg/l. The recommended guideline value of 1200mg/L for TDS by WHO (2011) is rather based on the taste effects of water rather than health. Excess alkalinity results to a distinct, flat and unpleasant taste and scale formation. The total compliance of sachet

water samples in this study contradict studies by Ashaye *et al.,* (2001) when they found out that sachet samples in Ibadan Nigeria, had low total dissolved solid contents. Addo *et al.,* (2009), Ampofo *et al.,* (2007) and Dodoo *et al.,* (2006) all recorded compliance with physical and chemical quality standards from studies conducted in various places in Ghana. The low values of TDS recorded could be as a result of the filtration of raw untreated water before packaging; this treatment process has the potential to reduce the concentration of TDS.

There were elevated mean nitrite concentrations in water samples from both production point (3.85 mg/L) and retail point (3.90 mg/L), exceeding the standard of 3 mg/L. At both points of production and retail, only sachet water samples from WA_7 and WA_3 met this criteria. Majority (75.25%) of these sachet water samples had exceeded the limit. This result is however in contrast to results obtained by Ackah *et al.,* (2012) in Accra, however Okafor and Ogbonna (2003) reported that 25% of sachet water samples in Nigeria had elevated nitrite concentrations. The high nitrite concentration in the samples could be attributed to a very high concentration of the compound in the raw untreated water which puts excessive stress on the treatment facilities hence its inability to reduce the concentration further. The high concentration in the raw untreated water could be from agricultural runoffs and domestic activities. Elevated nitrite in drinking water can lead to methemoglobinemia, a condition where nitrite binds to haemoglobin reducing the bloods ability to carry oxygen, This condition is most common in infants than adults because of their (infants) low stomach acidic content. Therefore 75% of these sachet water samples are not wholesome for consumption especially for babies(WHO, 2007).Fluoride in drinking water may bebeneficial or detrimental depending on its concentration and total amount ingested. The chronic and toxic effectsof excessive intake of fluoride are

usually observed as dental fluorosis and skeletal abnormalities. It is an essential substance in water for building healthy teeth when up to 1 mg/L. It is beneficial particularly to infants and young children for the calcification of dental enamel when present within the WHO (2011) permissible range of 0.5 to 1.5 mg/L (Kumar *et al.*, 2007). However, excess calcium and magnesium ions make water hard (Tay, 2007) In general the sachet water samples possessed good physicochemical characteristics (Asamoah and Amorin,2011; Onweluzo and Akuagbazie, 2010).

5.2 MICROBIAL QUALITY OF SACHET WATER.

It is worth noting that at the point of retail this study did not record any microbial contamination of the water samples. However at the production point, three samples; WA_{10}, WA_7 and WA_5 were contaminated with total coliforms, this again can be attributed to the difference in the batch of the water samples at the production point and retail point on the day of sampling. Ampofo *et al*., (2007), Dodoo *et al.,* (2006) and Obiri-Danso *et al.,* (2003) all reported all contamination of sachet water sold in Ghana with total coliforms in ranges similar to the results reported by this study. This contamination was only reported at the point of production (1 cfu/100ml for WA_{10} and WA_7 and then 2 cfu/100ml for WA_5) and therefore raises issues of hygiene at these places. Total coliforms are widely used as indicators of the general sanitary quality of treated drinking water while faecal coliforms give a much closer indication of faecal pollution (Ashbolt *et al*, 2001). These contaminated samples might have being an indication of contamination of a whole batch of sachet water produced that day and therefore could affect a larger proportion of the public. This contamination of the water with bacterial pathogens could be attributed to poor hygiene practices at the factories. Also this may be due to the inability of the filtration systems to effectively remove all bacterial pathogens from the raw untreated water. Defects in the

disinfection process, due to insufficient amount of chlorine added or faulty UV system may also contribute to bacterial pathogens in the sachet water. Sachet water could act as carriers of bacterial pathogens therefore there is the need to eliminate any forms of contamination most especially at the point of production. In Nigeria, Nwachukwu and Emeruem (2007), reported that bacteria isolates from sachet water were even in some cases resistant to eight common antibiotics, this gives an indication of the public health issues that could be attributed to bacterial contamination of sachet water. A study conducted in Lagos, Nigeria revealed that, bacteriological characteristic of sachet water deteriorates considerably as products moved farther down the distribution chain. Less than 7% of sachet water contamination took place after production while between 40 and 45% of the products were observed between the distribution sheds and the street hawkers (Omalu et al.,2010)

CHAPTER SIX

6.0: CONCLUSSION AND RECOMMENDATIONS

6.1: CONCLUSSION

Sachet water plays an important role in providing readily accessible water to the general populace; however the quality of this water must be of paramount interest to all, producers, consumers and regulatory authorities alike. From this study it can be said that sachet water sold in the Techiman Municipality recorded elevated nitrite concentration in almost all, except two and also low pH in some cases. The presence of total coliforms in some of the brands of water analyzed raises concern over the wholesomeness of these sachet waters as it has been shown from studies elsewhere that sachet water can be an avenue for transmission of antibiotic resistant bacteria.

6.2: RECOMMENDATIONS

1. Further studies should be conducted within the area to determine the sources of bacterial contamination.

2. The Ghana Urban Water Company Limited and The Food and Drugs Authority should carry out thorough checks on the facilities of these water producers before licensing them.

3. The regulatory authorities mentioned above should undertake routine checks of licensed sachet water seller.

4. The producers of these sachet water should also be sensitized on the need to keep their premises neat to prevent contamination.

REFERENCES

222Laws, E. A. (2000). Acquatic Pollution. Introductory Text. New Yorki: John Wiley and Sons p430. ISBN 978-0-471-34875-7

Addo, K. K., Mensah, G. I., Bekoe, M., Bonsu, C. &Akyeh, M. L (2009).Bacteriological quality of sachet water produced and sold in Teshie-Nungua suburbs of Accra, Ghana. *African Journal of Food Agriculture Nutrition and Development 9*, 1019–1030.

American Public Health Association(APHA). (1995), Standard Methods for the Examination of Water and Waste Water, 19[th]Edn., American Public Health Association, Washington, D. C.

Ampofo, J. A., Andoh, A., Tetteh, W. & Bello, M.(2007).Microbiological quality and health risks of packaged water produced in Southern Ghana. *Journal of Applied Science and Technology (JAST)* 12, 88–97.

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. Environmental International. 27; 597-604.

Anwar, J (1993). How safe is drinking water in Bangladesh? Bangladesh Observer 22 January 1993.Accessed on 23rd March, 2014.

Asamoah, D.N. and R. Amorin,(2011). Assessment of the quality of bottled/sachet water in the Tarkwa-Nsuaem municipality (TM) of Ghana. *Res. J. Appl. Sci. Eng.Technol.,* 3(5): 377-385

Ashaye, O. A., Couple, A. A., Afolabi, O. O. & Fasoyiro, S. B.(2001).Physicochemical properties of pure water samples in South-Western Nigeria. *Journal of Food Technology in Africa* 4,119–120.

Ashbolt N J, Grabow W K. and Snozzi M. (2001).Indicators of microbial water quality. In: Water Quality Guidelines: Guidelines, Standards and Health. *Fewtrell L. and Bartram J. (Ed). World Health Organization Water Series. IWA Publishing, Londo*n. pp 289-315.

CDC (2006). National Immunization Program. Available at: http://www.cdc.gov/nip

CDC (2006). Safe Water Systems (SWS), Centre for Disease Control and Prevention (CDC).

Clasen, T., W. P. Schmidt, T. Rabie, I. Roberts and S. Cairncross,(2007). Intervention to Improve Water Quality for Preventing Diarrhoea: Systematic Review and Meta-Analysis. British Medical Journal 334:782-791.

Diersing, Nancy (2009). "Water Quality: Frequently Asked Questions". *PDA*.NOAA. http://floridakeys.noaa.gov/pdfs/wqfaq.pdf. Retrieved 2009-08-24.

Dodoo, D. K., Quagraine, E. K., Okai-Sam, F., Kambo, D. J. &Headley, J. V.(2006).Quality of 'Sachet' waters in the Cape Coast municipality of Ghana. *Journal of Environmental Science and Health Part a-Toxic/Hazardous Substances & Environmental Engineering* 41, 329–342.

Doe, H. W. D. (2007).Assessing the Challenges of Water Supply in Urban Ghana.The Case Study of North-Teshie.MSc Thesis, Department of Lands and Water Resources Engineering, Royal Institute of Technology, Stockholm, Sweden.

Englebrecht, R.S and Greening M.ED. (1978). Chlorine resistant indicators in: Indicators of viruses in water and food. G. Berg (ed); *Ann Arbor Science Publications, Ann Arbo*r, p 243-265.

Environmental Science and Technology Vol. 4(10) pp.691-697, October 2010.

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

Ghana Statistical Service(2010). Population and Housing Census (PH). Analytical Report for the Techiman Municipality

Greenhalgh,A.,(2001)"Healthy Living Water" BBC Health.htt;//WWW.bbc.co.uk/ health/healthy_living/nutrition/drinks_water.shtml.

Gulta D. P., Sunita & Saharan J. P. (2009). Physico chemical analysis of ground water of selected area of kaithalcity (Haryana) India. *Researcher, 1*(2), 1-5.

GWRC. (2008). State of Science Report: Energy and Resource Recovery from Sludge, In; Y. Kalogo and H. Monteith (eds), Report for the Global Water Research Coalition, WERF and STOWA, Alexandria, VA, USA.

Harvey Creek 400,000G Reservoir Preliminary Structural Assessment-March 21, 2006.

Hogan, (2010). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions

Hogan, (2010). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions.

IDLO, GUARDIANSHIP, INHERITANCEANDLANDLAWINPOST-TSUNAMI ACEH (2006) available at http://www.idlo.int/documents/Guidebook% 20PDF.pdf

Ifabiyi,I.P.,(2008). Seft Purification of Freshwater Stream in Ille-Ife;Lession for Water Management Department of Geography,University of Ilorin,Ilorin,Nigeria,J.Hum.Ecol.,24(2;131-`137).

Ife North Local Government Area of Ogun State Nigeria. African Journal of

International Conference on Water and the Environment Report, (1992). Accessed from http://www.wmo.int/pages/prog/hwrp/documents/english/icwedece.html

Karanth, K. R.,(1987). Ground Water Assessment Development and Management. Tata McGraw Hill Publishing Company Ltd. New Delhi, pp725-726.

Kataria, H. C. Quershi, H. A., Iqbal, S. A. and Shandilya, A. K. (1996), Assessment of Water quality of Kolar Reservoir in Bhopal (M. P.). Pollution Research. 15(2), pp. 191-1936.

Kortatsi, B. K. (2006). Hydrochemical Characterization of Ground Water in Accra Plains of Ghana. Environmental Geology Journal. Vol. 50.pp 299-311.

Krishnamurthy, R. (1990). Hydro-biological Studies of Wohar Reservoir, Aurangabed (Maharashtra State) India. Journal of Environmental Biology, 11(3), 335-343.

Kumar, S., A. Gupta and J.P. Yadav, (2010). Fluoride removal by mixtures of neem(*Azadirachta indica*) and kikar (*Acacia Arabica*) leaves. *Indian J. Chem. Tech.*,14: 355-361.

Nwachukwu, E. &Emeruem, C. M. (2007). Presence of antibiotic resistant bacteria in sachet water produced and sold in Eastern Nigeria. *Research Journal of Microbiology* 2, 782–786.

Obiri-Danso Adjei , K. B, Stanley K.N. & Jones, K. (2008).The microbiological quality and metal levels in wells and boreholes water in some peri – urban communities in Kumasi. African journal of environmental science and technology. *Volume 3 (1) pp 059 – 066 , march 2009.*

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

Okafor, P. N. & Ogbonna, U. I. (2003), Nitrate and Nitrite Contamination of Water Sources and Fruit Juices Marketed in South-East Nigeria, J. Food Comp. Anal. 16:213-218

Oluyemi, E. A. (2010). Physiochemical Properties of Heavy Metal Content of Water Sources

Omalu, I.C.J., I.K. Olayemi, S. Gbesi, L.A. Adeniran, A.V. Ayanwale, A.Z. Mohammed and V.Chukwuemeka,(2010). Contamination of sachet water in Nigeria: Assessment and health impact. *Online J. Health Allied Sci.,* 9(4): 1-3.

Oyedeji O., Olutiola P. O. and Moninuola M. A. (2009). Microbiological quality of packaged drinking water brands marketed in Ibadan metropolis and Ile-Ife city in South-western Nigeria. www.academicjournals.org/ajmr (accessed 2011 March 12th)

Pink, D. H. (2006): Investing in Tomorrow's Liquid Gold.*Yahoo.http://finance.yahoo. com/columnist/article/trenddesk/3748.*

Premlata, Vikal. (2009). Multivariant analysis of Drinking Water Quality Parameters of Lake Pichhola in Udaipaul, India. Biological Forum, -An International Journal, 1(2), pp97-102

Prescott L M, Harley J P. and Klein D. A. (1999).The influence of environmental factors on growth.Microbiology.4th Edition. McGraw-Hill Companies, Inc., USA, pp. 123-132.

Retrieved May 01, 2007, from http://www.cdc.gov.safewater/

Rudolf, A.S. and Levine, M. (1941). Factors affecting the germical efficiency of hypochlorite solutions. *Eng Exp Stu Bull* 50.

Rutz, D.,(1996). Pure water vending machines may be so pure. *CNN: Food and Health*, May 2.

Schueler, T.R., and Holland, H.K.,(2000).Microbes in Urban Watershed; Concentration, Sources and Pathways. In The Practice of Watershed Protection Ed. Schueler, T. and Holland, H. pp 74-84.Ellicot City, MD; Center for Watershed Protection.

Snyder, J. D., and Merson, M. H. (1982). The Magnitude of the Global Problems of Acute Diarrhoea Disease; A Review of Active Surveillance Data. Bulletin of The World Health Organization, 60(4), 605-613.

Stockholm Environmental Institute (1993). Environmental problems and the urban household in the Greater Accra Metropolitan Area (GAMA)-Ghana.

Tay, C.K., (2007). Chemical characteristics of ground water in the Akatsi and Ketu Districts of the Volta Region, Ghana. *West Afr. J. Appl. Ecol*., 11: 1-23.

Third World Forum on water (2003). Blockade, Myth, Illusions in Development and Cooperation. Tokyo, Japan, Vol.30.

Umar, R., Ahmed, I., Alan, F. and Khan, M. M. (2009). Hydrological Characteristics and Seasonal Variations in Groundwater Quality of an Alluvial Acquifer in Parts of Central Ganga Plain, Western Uttar Pradesh, India-Environ Geol 58:1295-1300.

Umar, S. (2006). Alleviating adverse effects of Water Stress on Yields of Sorghum, Mastard and Groundnut by Potassium Application. Pak. J. Bot., 38(5): 1373-1380.

UNDP (2006). Human Development Report 2006. Beyond Scarcity: Power, Poverty, and the Global Water Crisis. London: Palgrave Macmillan for United Nations Development Programme.

United Nations Development programme.(2004). Clean Water and Sanitation for The Poor [online]. United Nations Development programme Available: http://www.undp.org./dpa/publications/fswater12030E.pdf.[16/10/2004].

USEPA. (2006). Drinking Water Contaminants, Basic Information about E.Coli 0157:H7 in Drinking Water, US Environmental Protection Agency website http://www.epa.gov/safewater/contaminants/ecoli.html(Accessed 03.01.07).

Water Aid Annual Report. (2008).pp4 , 12.

WHO (1993).Nitrate and Nitrite in drinking Water. Background Document for Development of WHO Guidelines for drinking water Quality. (WHO/SDE/WSH/07.01/16/Rev/1

WHO (2004). Safe piped water-Managing microbial water quality in piped distribution system. Geneva, World Health Organization.

WHO, (2011).Guidelines for Drinking-Water Quality. Word Health Organisation, Geneva, Switzerland.

WHO/UNICEF (2010).Joint Monitoring Programme for Water and Sanitation. ISBN 978 92 4 1563956 NLM Classification: WA 670

WHO/UNICEF. *Water for Life: Making It Happen*; WHO: Geneva, 2005.

World Health Organisation (2007). Chemical safety of drinking water: Assessing priorities for risk management. WHO, Geneva, Switzerland.

World Health Organisation (WHO).(1993). *Guidelines for drinking water quality.Revision of the 1984 guidelines. Final task group meeting. Geneva, 21–25 September 1992.*

World Health Organization (WHO).(1984). *Guidelines for drinking-water quality*. Vol. 2.Health criteria and other supporting information. Ch. 16. Geneva. pp. 145-15.

Zaslow A. S. and Herman G. M. (1996).Water quality and waste management. Health effects of drinking water contaminants. Published by: North Carolina Cooperative Extension Service Publication Number: HE-393.

Zuane De John,(1990). Drinking Water Quality: Standards and Controls. http;//www.env.gov.bc.ca

Sample 1: Production source.

CODE	pH	TEMP.℃	COND.$\mu s/cm$	TDSMg/l	TSS Mg/l	TH Mg/l	ALK.	COL. TCU	TUR. NTU	F^-	Cl^-	Fe^+	Cu	NO_3^-	NO_2^-	SO_4^-	PO_4^-	T. Col.	E. Coli
WA$_1$	7.53	25.3	17.5	22.5	1	48	6	9	2.00	0.14	0.5	0.003	0.002	12	4	11	1.08	ND	ND
WA$_2$	7.25	25.2	7.8	10.1	1	28	8	2	1.06	0.17	0.4	0.002	0.003	9	5	9	0.53	ND	ND
WA$_3$	6.71	25.1	16.5	21.0	1	52	9	2	1.06	0.21	0.5	0.011	0.016	11	1	9	0.67	ND	ND
WA$_4$	7.09	25.0	8.7	110.0	1	36	10	3	1.00	0.17	0.5	0.006	0.006	15	3	9	0.36	ND	ND
WA$_5$	6.86	25.1	29.2	372.0	2	24	6	8	1.61	0.17	0.3	0.003	0.001	30	6	8	0.43	ND	ND
WA$_6$	7.30	25.2	21.1	27.0	4	20	6	8	1.00	0.23	0.7	0.006	0.004	28	6	8	0.56	ND	ND
WA$_7$	6.83	25.2	27.1	345.0	1	48	6	4	1.04	0.20	0.6	0.010	0.002	19	2	9	0.35	ND	ND
WA$_8$	7.16	25.1	8.3	10.7	1	20	10	9	2.10	0.16	0.4	0.002	0.004	8	3	9	0.84	ND	ND
WA$_9$	6.93	25.2	6.1	78.9	1	36	5	7	1.01	0.20	0.4	0.001	0.002	11	4	8	0.38	ND	ND
WA$_{10}$	5.08	25.1	11.0	140.0	1	32	8	6	1.00	0.17	0.4	0.001	0.001	3	4	8	0.38	ND	ND

Sample 1: Retail Source.

CODE	pH	TEMP. $^\circ$C	COND. $\mu s/cm$	TDS Mg/l	TSS Mg/l	TH Mg/l	ALK.	COL. TCU	TUR. NTU	F^-	Cl^-	Fe^+	Cu	NO_3^-	NO_2^-	SO_4^-	PO_4^-	T. Col.	E. Coli
WA$_1$	7.52	25.4	17.4	22.5	1	49	6	9	2.00	0.14	0.5	0.003	0.002	12	4	11	1.09	ND	ND
WA$_2$	7.52	25.1	7.8	10.2	1	28	9	2	1.07	0.17	0.4	0.002	0.003	9	6	9	0.54	ND	ND
WA$_3$	6.70	25.2	16.6	21.0	1	52	9	2	1.06	0.21	0.5	0.011	0.016	11	1	9	0.67	ND	ND
WA$_4$	7.07	25.0	8.7	110.0	1	38	10	3	1.01	0.17	0.5	0.006	0.005	15	4	9	0.35	ND	ND
WA$_5$	6.84	25.3	29.3	370.0	3	25	6	8	1.60	0.17	0.3	0.003	0.002	30	6	8	0.44	ND	ND
WA$_6$	7.20	25.1	21.1	26.9	4	20	6	7	1.02	0.02	0.7	0.006	0.004	29	6	8	0.54	ND	ND
WA$_7$	6.84	25.3	27.1	345.0	1	48	6	4	1.04	0.20	0.6	0.002	0.001	19	2	9	0.36	ND	ND
WA8	7.16	25.0	8.2	10.7	2	22	10	9	2.02	0.16	0.4	0.002	0.004	9	4	8	0.80	ND	ND
WA$_9$	6.92	25.2	6.2	78.8	1	36	5	7	1.01	0.21	0.4	0.001	0.001	4	3	9	0.40	ND	ND
WA$_{10}$	5.08	25.0	11.0	141.0	1	33	9	7	1.02	0.17	0.5	0.001	0.001	3	4	8	0.39	ND	ND

Table 2: Production Source.

CODE	pH	TEMP.	COND.	TDS	TSS	TH	ALK.	COL.	TUR.	F^-	Cl^-	Fe^+	Cu	NO_3^-	NO_2^-	SO_4^-	PO_4^-	T.	E.
		°C	$\mu s/cm$	Mg/l	Mg/l	Mg/l		TCU	NTU									Col.	Coli
WA_1	7.54	25.4	17.6	22.50	2	48	7	8	2.00	0.14	0.5	0.003	0.002	12	4	12	1.08	ND	ND
WA_2	7.25	25.4	7.9	10.16	1	20	10	2	2.01	0.16	0.4	0.002	0.003	8	4	8	0.54	ND	ND
WA_3	6.72	25.2	16.5	20.87	2	53	9	2	1.07	0.22	0.5	0.001	0.016	12	1	9	0.57	ND	ND
WA_4	7.06	25.0	8.6	104.2	1	37	10	3	1.01	0.17	0.4	0.003	0.004	15	3	8	0.35	ND	ND
WA_5	6.84	25.1	28.6	350.2	2	24	6	7	1.52	0.16	0.3	0.002	0.001	30	6	8	0.44	ND	ND
WA_6	7.40	25.0	21.2	26.9	4	20	6	8	1.01	0.24	0.6	0.006	0.004	28	6	9	0.52	ND	ND
WA_7	6.8	25.1	28.0	345.2	1	46	7	4	1.03	0.20	0.3	0.010	0.001	18	2	9	0.36	ND	ND
WA8	7.14	25.0	8.4	10.6	2	22	10	8	2.10	0.16	0.2	0.002	0.004	9	3	8	0.82	ND	ND
WA_9	6.87	25.1	6.5	77.8	1	14	5	6	1.02	0.13	0.1	0.002	0.002	11	4	9	0.36	ND	ND
WA_{10}	5.8	25.1	11.0	138.4	3	34	7	6	1.01	0.17	0.2	0.001	0.001	4	3	8	0.40	ND	ND

Sample 2: Retail Source.

CODE	pH	TEMP.	COND.	TDS	TSS	TH	ALK.	COL.	TUR.	F^-	Cl^-	Fe^+	Cu	NO_3^-	NO_2^-	SO_4^-	PO_4^-	T.	E.
		°C	$\mu s/cm$	Mg/l	Mg/l	Mg/l		TCU	NTU									Col.	Coli
WA_1	7.5	25.5	17.6	23	1	48	7	8	2.00	0.10	0.5	0.002	0.002	12	4	12	1.1	ND	ND
WA_2	7.2	25.5	7.9	10	2	20	10	2	2.00	0.20	0.4	0.002	0.003	9	4	8	0.5	ND	ND
WA_3	6.7	25.4	16.5	21	1	53	9	2	1.07	0.22	0.5	0.001	0.016	12	1	9	0.6	ND	ND
WA_4	7.1	25.2	8.6	104	2	37	10	3	1.01	0.20	0.4	0.003	0.004	15	3	8	0.4	ND	ND
WA_5	6.8	25.2	28.6	350	0	24	6	7	1.52	0.20	0.3	0.002	0.001	30	6	8	0.4	ND	ND
WA_6	7.4	25.1	21.2	27	4	20	6	8	1.01	0.20	0.6	0.006	0.004	28	6	9	0.5	ND	ND
WA_7	6.8	25.2	28.0	345	1	46	7	4	1.03	0.20	0.2	0.001	0.001	18	3	9	0.4	ND	ND
WA8	7.1	25.1	8.4	11	1	22	10	8	2.10	0.20	0.2	0.002	0.003	9	4	8	0.8	ND	ND
WA_9	6.9	25.2	6.5	78	0	14	5	6	1.02	0.13	0.1	0.002	0.002	11	3	9	0.4	ND	ND
WA_{10}	5.8	25.2	11.0	138	2	34	7	6	1.01	0.00	0.2	0.001	0.001	35	3	9	0.4	ND	ND

Sample 3: Production Source.

CODE	pH	TEMP. °C	COND. $\mu s/cm$	TDS Mg/l	TSS Mg/l	TH Mg/l	ALK.	COL. TCU	TUR. NTU	F^-	Cl^-	Fe^+	Cu	NO_3^-	NO_2^-	SO_4^-	PO_4^-	T. Col.	E. Coli
WA$_1$	7.52	25.3	17.3	22.55	1	17	11	2.0	2.00	0.12	0.10	0.006	0.002	0.07	0.040	11	1.56	ND	ND
WA$_2$	7.29	25.2	7.9	10.11	1	21	8	2.0	1.06	0.16	0.10	0.003	0.002	0.05	0.017	9	1.49	ND	ND
WA$_3$	6.76	25.2	16.6	21.00	1	14	6	1.8	1.05	0.11	0.12	0.003	0.014	0.05	0.015	9	1.70	ND	ND
WA$_4$	7.03	25.2	8.8	110.00	2	15	7	1.9	1.00	0.13	0.11	0.003	0.006	0.06	0.011	9	1.62	ND	ND
WA$_5$	6.88	25.3	29.3	377.10	3	19	6	2.0	1.61	0.14	0.10	0.002	0.002	0.08	0.006	8	1.49	ND	ND
WA$_6$	7.34	25.2	21.4	27.01	3	13	6	2.0	1.00	0.17	0.12	0.003	0.003	0.11	0.010	9	1.55	ND	ND
WA$_7$	6.86	25.3	27.1	346.30	3	11	3	1.7	1.04	0.19	0.30	0.002	0.002	0.09	0.013	8	1.62	ND	ND
WA8	7.19	25.3	8.4	10.66	1	14	7	1.8	2.10	0.17	0.20	0.004	0.004	0.13	0.015	8	1.48	ND	ND
WA$_9$	6.95	25.3	6.3	77.80	1	14	5	2.0	1.01	0.13	0.10	0.001	0.001	0.06	0.021	8	1.53	ND	ND
WA$_{10}$	5.15	25.2	11.6	141.30	1	13	4	1.9	1.00	0.16	0.21	0.002	0.002	0.10	0.023	8	1.61	ND	ND

Sample 3: Retail Source.

CODE	pH	TEMP. $\,^\circ\text{C}$	COND. $\mu s/cm$	TDS Mg/l	TSS Mg/l	TH Mg/l	ALK.	COL. TCU	TUR. NTU	F^-	Cl^-	Fe^+	Cu	NO_3^-	NO_2^-	SO_4^-	PO_4^-	T. Col.	E. Coli
WA_1	7.52	25.3	17.3	22.6	1	17	11	1.9	2.00	0.12	0.10	0.006	0.002	0.07	0.040	11	1.55	ND	ND
WA_2	7.29	25.2	7.9	10.1	1	21	8	1.8	1.06	0.16	0.10	0.003	0.002	0.05	0.017	8	1.49	ND	ND
WA_3	6.76	25.2	16.6	21.0	1	14	6	2.0	1.05	0.11	0.12	0.003	0.014	0.05	0.015	9	1.70	ND	ND
WA_4	7.03	25.2	8.8	110.0	1	15	7	2.0	1.00	0.13	0.11	0.003	0.006	0.06	0.012	9	1.63	ND	ND
WA_5	6.88	25.2	29.3	377.0	2	19	6	1.8	1.61	0.14	0.12	0.002	0.002	0.08	0.006	9	1.49	ND	ND
WA_6	7.34	25.2	21.4	27.0	3	13	6	2.0	1.00	0.17	0.30	0.003	0.003	0.11	0.010	8	1.55	ND	ND
WA_7	6.86	25.2	27.1	334.6	3	11	3	1.9	1.04	0.19	0.20	0.002	0.002	0.09	0.021	8	1.60	ND	ND
WA8	7.19	25.2	8.4	10.7	1	14	7	1.9	2.10	0.17	0.20	0.004	0.004	0.13	0.014	8	1.46	ND	ND
WA_9	6.95	25.2	6.3	77.8	1	14	5	2.0	1.01	0.13	0.10	0.001	0.001	0.06	0.020	9	1.52	ND	ND
WA_{10}	5.15	25.1	11.6	141.0	1	13	4	1.8	1.00	0.16	0.21	0.002	0.002	0.17	0.023	9	1.61	ND	ND