KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY. KUMASI, GHANA

COLLEGE OF SCIENCE

ASSESSMENT OF THE QUALITY OF SOME SACHET WATER BRANDS IN THE SUNYANI METROPOLIS OF GHANA

A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL SCIENCE

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE

BY

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DECLARATION

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

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ABSTRACT

The study assessed the quality of the most patronised sachet water in the Sunyani Metropolis of Ghana. Six sachet water products were selected based on consumers' responses to a questionnaire survey. Samples of the products were purchased and stored for monthly phusico – chemical, nutrient and microbiological analyses for the period of two months. The analyses were done according to standard methods for the examination of water and wastewater. The result indicated that physic-chemical and nutrient levels were all within the World Health Organization (2007) and the Ghana Standards Authority (1998) permissible limits. The bacteriological analysis also showed that all brands of sachet water studied were not contaminated except for total coliform which was recorded in one of the product at a level of 9.1MPN / 100ml. No significant differences were recorded during the month of storage among the same brands. However, for the physico-chemical parameters,differences in mean values were significant for the different brands. Thus, it can be concluded that the sachet water products studied in the metropolis is generally of good quality. Nonetheless, sachet water products in the metropolis should be monitored regularly for microbial quality in order not compromise the standards.

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DEDICATION

This work is dedicated to my husband (Frederick Frimpong), My Uncles Mr. Raymond Ackabah and Mr. Emmanuel Anatsui.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Safe drinking water is essential to humans and other life forms even though it provides no calories or organic nutrients. Access to safe drinking water has improved over the last decades in almost every part of the world, but approximately one billion people still lack access to safe drinking water and over 2.5 billion lack access to adequate sanitation (WHO and UNICEF, 2010).

The human body contains from 55 to 78% water, depending on body size. To function properly, the body requires between one and seven litres of water per day to avoid dehydration; the precise amount depends on the level of activity, temperature, humidity, and other factors. Most of this is ingested through foods or beverages other than drinking straight water. It is not clear how much water intake is needed by healthy people, though most specialists agree that approximately 2 litres (6 to 7 glasses) of water daily is the minimum to maintain proper hydration (UTZ, 2000).

Water for drinking should be free of disease-causing microorganisms, harmful chemicals, objectionable taste and odour, excessive levels of colour and suspended materials. Ideally, the characteristics of water should not impair its aesthetic values (Maher *et al.,* 1997). Common impurities include metal salts and oxides, metals, including copper, iron, calcium and lead, and/or harmful bacteria. Some solutes are acceptable and even desirable for taste enhancement and to provide needed electrolytes (Maton *et al.*, 1993).

The high frequency of diseases such as diarrhoea, typhoid fever, cholera and bacillary dysentery among the populace has been traced to the consumption of unsafe water and unhygienic drinking water production practices (Maed *et al*., 1999). Water borne diseases continue to be one of the major health problems in developing nations especially on the issue of safe drinking water quality (Mead *et al.,* 1999). The number of outbreaks that have been reported throughout the world demonstrates that transmission of pathogens by drinking water remains a major cause of illness.

Plastic bagged drinking water was introduced into the Ghanaian market as a less expensive means of accessing drinking water than bottled water. The plastic bagged water is an improvement over the former types of bagged drinking water packaged for sale (hand-filled-hand-tied polythene bagged or a plastic cup in a bucket of water with ice blocks). Today, the easy accessibility to drinking water in packaged forms has resulted in a big and flourishing water production enterprise with hundreds of millions of litres of these water products consumed every year by the populace (Ogundipe, 2008).

Plastic bagged drinking water brands have outnumbered the bottled water brands because of its easy accessibility and affordability. The increase in demand for packaged water has also been attributed to changes in lifestyle towards the consumption of "designer water", increased concerns of the safety of municipal water and an increased influx of people into major urban areas with a dire need for good drinking water (Hunter, 1994). In addition, convenience has also made the products to meet the requirements of any lifestyle when needed (Gardner, 2004).

The raw water for the production of bottled and sachet water in Ghana is mostly obtained from pipe-borne water, springs and groundwater (Obiri-Danso *et al.,* 2003). Manufacturers employ different standards of hygiene in the various stages of production of plastic bagged sachet water. Most manufacturers use multi-candle pressure filters, which employ an active carbon filter bed that removes sand, rusts, metal sediments, algal films and bacteria from the water (Hunter and Burge 1987). The bags are closed using heat-sealing machines. Several studies on the microbial quality of plastic bagged sachet water have reported violations of international quality standards (Obiri-Danso *et al.*, 2003; Bharath *et al*., 2003; Warburton *et al*., 1986). The presence of faecal coliforms observed in packaged drinking water has been reported to be due to poor hygienic practices of producers and ignorance about effective water treatment technologies (Coroler *et al.*, 1996). Filter systems with poor maintenance practices in water processing companies are also a possible source of contamination because bacteria can grow on filters if they are not changed regularly, and thereafter enter the water supply (Hunter and Burge, 1987).

Consumers normally purchase sachet water without any knowledge of the quality of its contents. Indeed, sachet water is a possible route for transmitting major diseases, both from its contents and the container. The introduction of sachet water in Ghana was to provide affordable instant drinking water to the public and to curtail the magnitude of communicable diseases in the country. It is also a potential source of infection in Ghana, a burden on the public health system and an environmental hazard. In Nigeria, for instance, which has had a similar market for sachet water as Ghana, the National Agency for Food and Drug Administration and Control (NAFDAC), the agency mandated to enforce compliance with internationally defined water guidelines has declared a possible nationwide gradual ban on sachet water because of the threat of contamination (Omalu *et al*., 2010). However, successful implementation of this ban is yet to manifest as the sachet water industry is experiencing tremendous growth, especially among poor and middle class social classes (Omalu *et al*., 2010).

1.2 Problem Statement

The sale and consumption of packaged water continues to grow rapidly in Sunyani 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).

An alarming percentage (85%) of the sachet water produced and sold in Ghana is not of standard quality as was revealed in a survey conducted by the Ghana Chemical Society (GCS, 2011). The survey relied on specifications set by the Ghana Standards Authority (GSA) which included raw material requirements, virological and parasitological qualities as well as packaging and labelling (Ghana Broadcasting Corporation report, 2011). This report led to the closure of some sachet water producing companies by the Food and Drugs Authority (FDA). In spite of this eminent threat and closure of some sachet water producing companies, the market for sachet water production and distribution keeps increasing. Coupled with this alarming rate of increase is the fact that majority of these people have little or no knowledge and experience in the production of water in commercial quantities under standard conditions (Daily Graphic Report, 2013). Most producers hide and produce. Some people have turned their boys' quarters into sachet water production factories and are producing only in the night. A sizeable number of the sachet water brands in the country, especially those in the hinterlands, are produced, distributed and consumed on the blind side of the GSA and the FDA – the institutions mandated to protect consumers against shoddy goods.

According to a Daily Graphic Report (2013), the country woke to news of a cholera outbreak in the national capital of Accra in early 2012. That was surprising, given that Ghana is thought to have come of age to be attacked by diseases emanating from improper hygienic conditions. As at the middle of 2012, the outbreak had spread nation-wide, claiming over 60 lives and threatening over 4,000 more people, according to reports from the Ghana Health Service at the time. Many health officers, including the Public Health Director of the Accra Metropolitan Assembly (AMA), blamed the outbreak partly on the production and sale of sachet water.

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 tendency to pose more of a chronic health risk, even though some components like nitrates and nitrites may have an acute impact. Thus, water used for sachet water production must be adequately treated to ensure acceptable levels of these minerals and other chemicals remain in the water. It is in the light of this that this study was conducted to assess the quality of sachet water sold in the Sunyani Municipality of Ghana.

1.3 Significance of the Study

This research was to highlight the quality standards that are being used by sachet water producers in Sunyani and its environs. This was to inform stakeholders and watchdogs at the centre of health in Ghana especially, the FDA of the state of drinking sachet water in Sunyani for proper sanctions to be implemented on the producers. Very importantly, this study was to serve as a contribution to academic knowledge pertaining to the water industry since there is limited documentation on the industry in Ghana.

1.4 Objectives of the study

The main objective of the study was to assess the quality of selected brands of sachet drinking water sold in the Sunyani Metropolis.

The specific objectives of the study were to determine;

- the most patronized brands of sachet water in Sunyani Metropolis.
- some physico-chemical parameters (pH, apparent colour, conductivity, turbidity, TDS, alkalinity and hardness) of the most patronized brands of sachet water in Sunyani Metropolis.
- the nutrient levels (nitrite, nitrate, phosphate, chloride and ammonia) of the most patronized sachet water in Sunyani Metropolis.
- the levels of total coliforms, faecal coliforms and *E. coli* in sachet water in Sunyani Metropolis.
- to assess consumers' perception on the quality of sachet water they consume.

CHAPTER TWO

LITERATURE REVIEW

2.1 The global need for clean water

A common definition of clean water is water that is devoid of pathogenic organisms, toxic substances, colour, turbidity, taste, and odour, and an acceptable level of minerals and organic material (Thanh and Hettiaratchi, 1982). Every human on our planet has a fundamental right to a reliable supply of clean water. Yet, according to the World Health Organization, there are still 1 billion people in the world without access to an improved water supply (WHO and UNICEF, 2010). This translates to 6% of the global population lacking access in urban areas, and 29% lacking access in rural areas. This is not only a critical problem in developing countries, but also a challenge faced by many municipalities in both rural and remote areas of the developed world. The results of inadequate water supply are catastrophic, as 2.2 million deaths related to diarrhea disease occur every year, which equates to one water-related death every 15 seconds (WHO and UNICEF, 2000). Thus, there is a global need for clean water and every man, woman, and child has a fundamental right to a reliable supply.

2.2 The Importance of Drinking Water Quality

Water is one of the indispensable resources for the continued existence of all living things including man. The provision of an adequate supply of safe drinking water was one of the eight components of primary health care identified by the International Conference on Primary Health care in 1978 (Edema *et al*., 2001). The changes in physical characteristics like temperature, transparency, suspended solids and chemical characteristics of water such as dissolved oxygen, chemical oxygen demand, nitrate and phosphate provide valuable information on the quality of the water (Mustapha, 2008). The existence of elevated levels of elements and organisms in drinking water constitutes poor water quality, which is a recipe for disease outbreaks (Ntengwe, 2003).

In the effort to protect citizens in urban areas, governments the world over must augment the quality of urban drinking water that is to be provided to their citizens (World Health Organisation, 1993). However, in the bid to maintain the quality of urban drinking water, the manufacturers have had to spend huge sums of money to pump, treat, package and distribute the water to the customers (Ntengwe, 2003). Any attempts that result in the reduction of costs to levels below the optimum costs would bring about abysmal drinking water quality.

A daily per capita consumption of two (2) liters is the generally accepted value for a person weighing 60 kg (World Health Organisation, 1998). This is the value used in estimating ingestion exposure to potentially hazardous chemicals in drinking water. The actual water intake, however, varies considerably from individual to individual and according to climate, physical activity and culture (Gadgil, 1998). Young children, pregnant and lactating women, the elderly, and people with certain illnesses may have increased fluid requirements (Howard *et al*., 2003).

Dehydration is the adverse consequence of inadequate water intake (Greenleaf and Harrison, 1986). The symptoms of acute dehydration vary with the degree of water deficit. For instance, fluid loss at 1% of body weight impairs thermoregulation and thirst occurs at this level of dehydration. Vague discomfort and loss of appetite appear at 2% (Greenleaf and Harrison, 1986).

Moreover, water consumption plays an important role in the digestion of solid foods in the body. Nutrients required for growth and repair of muscle tissues are also transported with the help of water in the blood stream. A copious amount of water is required daily to keep this entire process going on (World Health Organisation, 2005). Health consequences of micronutrient deficiencies include increased morbidity, mortality due to reduced immune defense systems and impaired physical and mental development. These nutritional deficiencies decrease worker productivity and increase the rates of disease and death in adults (World Health Organisation, 2005).

2.3 The advent of sachet water

Water vending has probably existed as long as society itself, and the issues surrounding vended water in the developing world have received contemporary review elsewhere (Sansom, 2004; Kjellén and McGranahan, 2006). In the 1970s and 1980s, it was common to buy a cup of drinking water on the streets of Accra and other towns and cities in Ghana. The purchaser drank directly from a plastic or metal cup, which the vendor used to scoop water out of a larger storage vessel. This form of water entrepreneurship was aimed at poor, transient population segments, but eventually demand grew beyond this demographic.

Increased demand coupled with the obvious sanitary shortcomings of such a system led to the packaging of water in small plastic bags in the 1990s. This, however, did not adequately address the hygienic quality of the water since bags were generally filled by women and children (Olayemi, 1999; Obiri-Danso *et al.*, 2003). In the late 1990s, new Chinese machinery that heat-sealed water in a plastic sleeve effectively created the modern sachet that is currently sold on the streets of several West African nations.

2.4 Water Treatment Requirements

The water treatment requirements in sachet water production are filtration and UV disinfection. At least five filters and one UV disinfection unit are required for each sachet machine. The filter cartridges are required to be changed at least once every three months.

Ultraviolet light is very effective at inactivating cysts, as long as the water has a low level of colour so the UV can pass through without being absorbed. The main disadvantage to the use of UV radiation is that, like ozone treatment, it leaves no residual disinfectant in the water. Because neither ozone nor UV radiation leaves a residual disinfectant in the water, it is sometimes necessary to add a residual disinfectant after they are used. This is often done through the addition of chloramines which is a primary disinfectant. When used in this manner, chloramines provide an effective residual disinfectant with very little of the negative aspects of chlorination (http://en.wikipedia.org/wiki/Water_purification).

Membrane filters are widely used for filtering drinking water. Membrane filters can remove virtually all particles larger than 0.2 um — including G*iardia* and *Cryptosporidium.* Membrane filters are an effective form of tertiary treatment when it is desired to reuse the water for industry, for limited domestic purposes, or before discharging the water into a river that is used by towns further downstream. They are widely used in industry, particularly for beverage preparation (including bottled water) (http://en.wikipedia.org/wiki/Water_ purification).

2.5 Production of Plastic Bagged Drinking Water

Tap water is collected into a reservoir and is treated with chlorine tablet. The water is then pumped into an overhead tank through four sets of filters with pore sizes of 5 microns each. The water descends or flows with force into four other sets of filters, two with pore size of 1 micron and the other two with pore size of 0.5 micron. The water then passes through carbon into a stainless steel ultraviolet machine before finally passing through a packaging machine where it is automatically packed into sachets (500 ml). In-built in the machine is an ultraviolet light that casts on the roll of the rubber for packaging.

The bags used for packaging factory produced plastic bag drinking water are made of high-density polyethylene (HDPE), which is very strong and has higher tensile strength difficult to elongate, and can withstand higher temperatures (Polyprint, 2007).

2.6 Brief concept of sachet water

Sachet water, viewed as the latest, low-cost technological incarnation of vended water in developing cities has allowed a steady evolvement of vended water. It has been noted through the review of literature that sachet drinking water is now prevalent in countries contiguous to Nigeria and Ghana (Cote d'Ivoire, Burkina Faso, Togo, Benin, Niger and Cameroon).

A recent body of literature highlights the challenges in maintaining quality control of machine vended water (i.e. filling personal containers) in the US and Europe (Chaidez *et al.*, 1999; Hunter

and Barrell, 1999; McSwane *et al*., 1994, Schillinger and Du Vall Knorr, 2004). Sachet drinking water has been important for low income households by eliminating the need for unsafe water storage vessels.

The deterioration of water quality during transport and storage is well established in public health literature (Clasen and Cairncross, 2004; Gundry *et al*., 2006; Wright *et al.*, 2004). The determination of the microbiological quality of water is essential in testing for the overall quality of water, which often involves the enumeration of bacteria of faecal origin (Luksamijarulkul, 1994). The contamination of water with infected faecal material is common in areas with poor standards of hygiene and sanitation (Luksamijarulkul *et al*., 1994).

2.7 The Consequences of Poor Drinking Water

Although water-related diseases have largely been eliminated in wealthier nations, they remain a major concern in much of the developing world (Gleick, 2002). The most dangerous form of water pollution occurs when faecal contaminants enter the water supply. Pathogens such as *Salmonella* species, *Shigella* species, *Vibrio cholera* and *Escherichia coli* being shed in human and animal faeces ultimately find their way into water supply through seepage of improperly treated sewage into ground water and other sources of drinking water (DiPaola, 1998).

A significant proportion of water-borne illnesses are likely to go unnoticed by the communicable diseases surveillance reporting systems. The symptoms of gastrointestinal illness (nausea, diarrhoea, vomiting and abdominal pain) are usually mild and generally last a few days to a week and only a small percentage of those affected will visit a health facility (Dufour *et al.*, 2003). Since many illnesses are undiagnosed and unreported, the true extent of these diseases is in the oblivion.

The minimum infectious dose, which represents the smallest number of ingested pathogens necessary to cause disease, for the average healthy adult varies widely for various microorganisms. This dose ranges from just a few organisms for *Salmonella typhi* to produce typhoid, several hundred organisms for *Shigella flexneri* to cause dysentery, several million cells of *Salmonella* serotype needed to cause Gastroenteritis, to as many as a hundred million cells of *Vibrio cholera* needed to produce Cholera (World Health Organisation, 1998). The minimum infectious dose also varies by the age, health, and nutritional and immunological status of the exposed individual. The infective doses are appreciably lower for debilitated, sick and elderly than for the general adult population (World Health Organisation, 1998).

2.8 Physico–chemical parameters of good drinking water

The appearance, taste, odour, and 'feel' of water determine what people experience when they drink or use water and how they rate its quality; other physical characteristics can suggest whether corrosion and encrustation are likely to be significant problems in pipes or fittings. The measurable characteristics that determine these largely subjective qualities are:

• True colour (i.e. the colour that remains after any suspended particles have been removed)

• Turbidity (the cloudiness caused by fine suspended matter in the water)

• Hardness (the reduced ability to get a lather using soap)

• Total Dissolved Solids (TDS)

• pH

• Temperature

• Taste and odour

•Dissolved oxygen.

Colour and turbidity influence the appearance of water. Taste can be influenced by temperature, TDS, and pH. The 'feel' of water can be affected by pH, temperature, and hardness. Rates of corrosion and encrustation (scale build-up) of pipes and fittings are affected by pH, temperature, hardness, TDS and dissolved oxygen.

2.8.1. pH of Drinking Water

pH is a measure of the acidity or basicity of an aqueous solution. Although the pH of pure water is 7, drinking water and natural water exhibits a pH range because it contains dissolved minerals and gases. Surface waters typically range from pH 6.5 to 8.5 while groundwater ranges from pH 6 to 8.5 (GSB, 1998). Water with a pH less than 6.5 is considered acidic. This water typically is corrosive and soft. It may contain metal ions, such as copper, iron, lead, manganese and zinc. The metal ions may be toxic, may produce a metallic taste, and can stain fixtures and fabrics. Water with a pH higher than 8.5 is considered basic or alkaline.

This water often is hard water, containing ions that can form scale deposits in pipes and contribute to an alkali taste.

The toxicity of metals is dependent on their solubility and on the presence of different types of anions and other cations (Abulude *et al.*, 2007). This is undesirable and can cause health concerns if concentrations of such metals exceed recommended limits (Putz, 2003).

pH is essential as an operational parameter, particularly in terms of the effectiveness of chlorination or optimizing coagulation. Acceptable pH for drinking water is between 6.5 and 8.5 and this is the range proposed as the guideline value (World Health Organisation, 1984; Ghana Standards Board, 1998).

2.8.2. Apparent Colour of Drinking Water

Colour in water is the result of dissolved extracts from metals in rocks and soil, from organic matter in soil and plants, and occasionally from industrial by-products. When colour is caused by metals, it is usually due to iron, copper, or manganese ions in the water (American Public Health Association, 1998). It may also be due to precipitation of soluble iron or manganese when they react with dissolved oxygen, chlorine disinfectant, and other oxidizing agents during water treatment. Consumers may turn to alternative, perhaps unsafe sources when their water is coloured to an aesthetically displeasing degree, hence it is desirable that drinking water should be colourless (World Health Organisation, 1984).

The term true colour is used to mean the colour of water from which turbidity has been removed. The term apparent colour includes not only the colour due to substances in solution but also that due to suspended matter (Putz, 2003). The guideline value of apparent colour is 15 Hazen units (Ghana Standards Board, 1998; World Health Organisation, 2007).

2.8.3 Conductivity of drinking water

Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulphate, and phosphate anions or sodium, magnesium, calcium, iron, and aluminum cations (APHA, 1992). Conductivity is therefore an indirect measure of the total dissolved solids (TDS) content of water, and there is usually an approximately linear relationship between TDS and conductivity. Conductivity measurements are used routinely in many industrial and environmental applications as a fast, inexpensive and reliable way of measuring the ionic content in a solution. The measurement of product conductivity is a typical way to monitor continuously the trend in the performance of water purification systems.

Increasing conductivity over time in water indicates that one or more inorganic constituents are also increasing and this situation should trigger further investigations (World Health Organisation, 2007). The guideline value proposed for conductivity is 150000 µS/cm (Ghana Standards Board, 1998; World Health Organisation, 2007).

2.8.4. Turbidity of Drinking water

Turbidity is the measure of relative clarity of a liquid. It is an optical characteristic of water and is an expression of the amount of light that is scattered by material in the water when a light is shined through the water sample. The higher the intensity of scattered light, the higher the turbidity. Material that causes water to be turbid includes clay, silt, finely divided inorganic and organic matter, algae, soluble colored organic compounds, and plankton and other microscopic organisms. Turbidity makes water cloudy or opaque (Zvikomborero, 2005).

Turbidity is commonly used as an indicator for the general condition of the drinking water. Particles in drinking water (suspended solids) are aesthetically objectionable, and can serve as shields for pathogenic microorganisms. Moreover, many toxic chemicals such as pesticides and heavy metals are selectively adsorbed on suspended particulate matter (Putz, 2003). The efficiency of disinfection may be reduced in the presence of high suspended solids and the disinfectant is unable to contact the target organism because of a physical barrier or chemical reactions with suspended solids, consequently decreasing the available disinfectant concentration (NHMRC–ARMCANZ, 1996). More chlorine is required to effectively disinfect turbid water. In the United States, systems that use conventional or direct filtration methods turbidity cannot be higher than 1.0 nephelometric turbidity units (NTU) at the plant outlet and all samples for turbidity must be less than or equal to 0.3 NTU for at least 95 percent of the samples in any month. Systems that use filtration other than the conventional or direct filtration must follow state limits, which must include turbidity at no time exceeding 5 NTU. Many drinking water utilities strive to achieve levels as low as 0.1 NTU. Turbidity above 5 NTU may be noticeable and consequently objectionable to consumers. The guideline value for turbidity is 5 NTU (Ghana Standards Board, 1998; World Health Organisation, 2007).

2.8.5. Total Dissolved Solids in Drinking Water

Total dissolved solids (TDS) in water refers to the residue remaining in a weighed dish after the sample has been passed through a standard fiber glass filter and dried to constant mass at 103 to 105 degrees Celsius. Many dissolved substances are undesirable in water (Putz, 2003). Dissolved minerals, gases and organic constituents may produce aesthetically displeasing colour, taste and odour.

The TDS in drinking water originate from natural sources, sewage, urban run-off, industrial wastewater, and chemicals used in the water treatment process, and the nature of the piping or hardware used to convey the water, i.e., the plumbing. In general, the total dissolved solids concentration is the sum of the cations and anions ions in the water. Therefore, the total dissolved solids test provides a qualitative measure of the amount of dissolved ions, but does not tell us the nature or ion relationships. In addition, the test does not provide us insight into the specific water quality issues, such as: elevated hardness, salty taste, or corrosiveness. Therefore, the total dissolved solids test is used as an indicator test to determine the general quality of the water.

Some dissolved organic chemicals may deplete the dissolved oxygen in the receiving waters and some may be inert to biological oxidation, yet others have been identified as carcinogens. Water with higher dissolved solids content often has a laxative and sometimes the reverse effect upon people whose bodies are not adjusted to them (Putz, 2003). As far as health aspects are concerned, there is no evidence of adverse physiological reactions at TDS levels greater than 1000 mg/L (World Health Organisation, 1993). The guideline value for TDS in drinking water is 1000 mg/L (Ghana Standards Board, 1998; World Health Organisation, 2007).

2.8.6. Dissolved Oxygen in Drinking Water

Dissolved oxygen (DO) refers to the volume of oxygen that is contained in water. Oxygen enters the water as rooted aquatic plants and algae undergo photosynthesis, and as oxygen is transferred across the air-water interface. The amount of oxygen that can be held by the water depends on the water temperature, salinity, and pressure. Therefore, measurements can only be used in a relative, not an absolute sense (World Health Organisation, 1984).

Dissolved oxygen is an important indicator of water quality. This is due to its importance as a respiratory gas, and its use in biological and chemical reactions (Mustapha, 2008). Dissolved oxygen in water primarily affects oxidation-reduction reactions involving iron, manganese, copper and compounds containing nitrogen and sulphur. However, large declines in dissolved oxygen in water could indicate high levels of microbiological activity, and should trigger further sampling for microorganisms (World Health Organisation, 2007). No guideline value is recommended because the acceptability of low levels of dissolved oxygen depends on the presence of other water constituents. The relationship between dissolved oxygen levels and water quality was studied by Ramachandra and Solanki (2006), and is cited in Table 1 below.

Table 1: Dissolved oxygen level and water quality

Dissolved Oxygen (mg/L)	**Water Quality**
Above 8.5	Good
6.6 – 8.5	Slightly polluted
4.5 -6.5	Moderately polluted
4.0 – 4.5	Heavily polluted
Below 4.0	Severely polluted

Ramachandra and Solanki (2006).

However it is desirable that dissolved oxygen levels be maintained as near saturation point (8 mg/L) as possible (World Health Organisation, 1984; Ghana Standards Board, 1998).

2.8.7. Alkalinity of drinking water

Alkalinity is a measure of water's ability to neutralize acids, and so is related to pH. It results primarily from carbonate minerals, such as those found in limestone, dissolving in the aquifer.

However, the major portion of the alkalinity in natural waters is caused by hydroxide, carbonate and bicarbonate (Ramachandra and Solanki, 2006).

Alkalinity and total hardness are usually nearly equal in concentration when both are reported in mg/L $CaCO_3$ (calcium carbonate), because they come from the same minerals. Alkalinity is not considered detrimental to humans but is generally associated with high pH values, hardness and excess dissolved solids. High alkalinity waters may also have a distinctly flat, unpleasant taste (Ramachandra and Solanki, 2006). Alkalinity is expressed as mg/L and there are no guideline value proposed by the World Health Organisation (Ghana Standards Board, 1998; World Health Organisation, 2007). The World Health Organization suggested guideline values for alkalinity as low (< 50mg/L as $CaCO_3$); medium (50-250 mg/L as $CaCO_3$), and high (>250 mg/L as $CaCO_3$).

2.8.8. Total hardness of drinking water

Hard water is water that has high mineral content. Hard water is formed when water percolates through deposits of calcium and magnesium-containing minerals such as limestone, chalk and dolomite. Public acceptability of the degree of hardness of water may vary considerably from one community to another depending on local conditions and in some instances, hardness in excess of 500 mg/L is tolerable (Putz, 2003). Hard water may assist in strengthening bones and teeth because of its high calcium concentration. It may also decrease the risk of heart diseases. Drinking water hardness must be above 8.4 mg/L (Putz, 2003). The guideline value for total hardness is 500 mg/L (Ghana Standards Board, 1998; World Health Organisation, 2007).

2.8.9. Magnesium ion and hardness of drinking water

Magnesium is a common constituent in natural water. A large number of minerals contain magnesium, for example dolomite (calcium magnesium carbonate; $CaMg(CO_3)_2$) and magnesite (magnesium carbonate; $MgCO_3$). Magnesium is washed from rocks and subsequently ends up in water. Magnesium has many different purposes and consequently may end up in water in many different ways. Chemical industries add magnesium to plastics and other materials as a fire protection measure or as filler. It also ends up in the environment from fertilizer application and from cattle feed. Magnesium sulphate is applied in beer breweries, and magnesium hydroxide is applied as a flocculant in wastewater treatment plants.

Magnesium salts are important contributors to the hardness of water which break down when heated, forming scale in boilers. Chemical softening, reverse osmosis, electrodialysis, or ion exchange reduces the magnesium and associated hardness to acceptable levels (Putz, 2003). Magnesium ion is important for the regulation of muscle contractions and the transmission of nerve impulses, and it activates energy-producing enzymes. Nervousness, lack of concentration, dizziness, and headaches or migraines may result from magnesium deficiency. Since a guideline value is proposed for total hardness, no guideline value is proposed for magnesium concentration in drinking water (World Health Organisation, 2007).

2.8.10 Calcium Ion and Hardness of Drinking Water

Calcium is a major constituent of various types of rock. It may dissolve from rocks such as limestone, marble, calcite, dolomite, gypsum, fluorite and apatite. Calcium is a determinant of water hardness, because it can be found in water as Ca^{2+} ions. It is one of the most common constituents present in natural waters ranging from zero to several hundred milligrams per liter depending on the source and treatment of the water (Putz, 2003). Calcium is largely responsible for water hardness, and may negatively influence toxicity of other compounds. Calcium carbonate has a positive effect on lead water pipes, because it forms a protective lead (II) carbonate coating. This prevents lead from dissolving in drinking water, and thereby prevents it from entering the human body. Calcium phosphate is a supporting substance and it causes bone and tooth growth, together with vitamin D. Bones decalcify (osteoporosis) and fractures become more likely if a body is not getting enough calcium. Since a guideline value is proposed for total hardness, no guideline value is proposed for calcium concentration in drinking water (World Health Organisation, 2007).

2.8.11. Phosphate in Drinking Water

Phosphates are chemical compounds containing phosphorus. Phosphates enter waterways from human and animal waste, phosphorus rich bedrock, laundry, cleaning, industrial effluents, and fertilizer runoff. These phosphates become detrimental when they over fertilize aquatic plants and cause stepped up eutrophication. Phosphorus is one of the key elements necessary for growth of plants and animals. Phosphates exist in three forms: orthophosphate, metaphosphate (or polyphosphate) and organically bound phosphate. Each compound contains phosphorous in a different chemical formula. Ortho forms are produced by natural processes and are found in sewage. Poly forms are used for treating boiler waters and in detergents. In water, they change into the ortho form. Organic phosphates are important in nature (Water Research Watershed Center, 2014).

Public water systems (PWSs) commonly add phosphates to the drinking water as a corrosion inhibitor to prevent the leaching of lead and copper from pipes and fixtures. Inorganic phosphates (e.g., phosphoric acid, zinc phosphate, and sodium phosphate) are added to the water to create orthophosphate, which forms a protective coating of insoluble mineral scale on the inside of service lines and household plumbing. The coating serves as a liner that keeps corrosion elements in water from dissolving some of the metal in the drinking water. The key to ensuring that orthophosphate reduces lead and copper levels is for PWSs to maintain proper orthophosphate levels. Phosphates are not toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphate. The guideline value for phosphate in drinking water is 400 mg/L (World Health Organisation, 2007).

2.8.12. Manganese in Drinking Water

Manganese is a mineral that naturally occurs in rocks and soil and is a normal constituent of the human diet. Manganese salts may impart an astringent taste to drinking water supplies and can give an aesthetically displeasing brown colouration to the water. When it is oxidized in aerobic waters, manganese precipitates as a black slimy deposit, which can build up in distribution to cause severe discolouration at concentrations above 0.05 mg/L (Putz, 2003).

Exposure to high concentrations of manganese over the course of years has been associated with toxicity to the nervous system, producing a syndrome that resembles Parkinsonism. This type of effect may be more likely to occur in the elderly. The health based guideline value is 0.4 mg/L (World Health Organisation, 2007) and 0.1 mg/L (Ghana Standards Board, 1998).

2.9 Nutrient Analysis of water

2.9.1. Chloride in Drinking Water

Chloride is one of the major inorganic anions in drinking water. In potable water, the salty taste is produced by the chloride concentrations and it is variable and dependent on the chemical composition (Putz, 2003). There is no known evidence that chlorides constitute any human health hazards. For this reason, chlorides are generally limited to 250 mg/L in supplies intended for public use. In many areas of the world where water supplies are scarce, sources containing as much as 2000 mg/L are used for domestic purposes without the development of adverse effects, once the human system becomes adapted to the water. Chloride concentrations in excess of about 250 mg/litre can give rise to detectable taste in water, but the threshold depends upon the associated cations. Consumers can, however, become accustomed to concentrations in excess of 250 mg/litre. However high chloride content may harm metallic pipes and structures (Putz, 2003). The guideline value of chloride in drinking water is 250 mg/L, based on taste considerations (Ghana Standards Board, 1998; World Health Organisation, 2007).

2.9.2. Ammonia in Drinking Water

Ammonia in the environment originates from metabolic, agricultural and industrial processes and from disinfection with chloramine. Natural levels in groundwater and surface water are usually below 0.2 mg/L. Anaerobic groundwaters may contain up to 3 mg/L. Intensive rearing of farm animals can give rise to much higher levels in surface water. Ammonia contamination can also arise from cement mortar pipe linings. Ammonia in water is an indicator of possible bacterial, sewage and animal waste pollution (World Health Organisation, 2003). The presence of ammonia at higher concentrations is an important indicator of faecal pollution. Taste and odour problems as well as decreased disinfection efficiency are to be anticipated if drinking water contains more than 0.2 mg/L of ammonia. When such water is chlorinated, as much as 68% of the chlorine may react with the ammonia and become unavailable for disinfection (World Health Organisation, 2007). The presence of the ammonium cation in raw water may result in drinking water containing nitrite as the result of catalytic action or the accidental colonization of filters by ammonium-oxidizing bacteria. The guideline value for ammonia in drinking water is 1.5 mg/L (Ghana Standards Board, 1998; World Health Organisation, 2007).

2.9.3. Nitrate-Nitrogen and Nitrite-Nitrogen in Drinking Water

Nitrogen is the nutrient applied in the largest quantities for lawn and garden care and crop production. In addition to fertilizer, nitrogen occurs naturally in the soil in organic forms from decaying plant and animal residues. In the soil, bacteria convert various forms of nitrogen to nitrate, a nitrogen/oxygen ion (NO_3^-). This is desirable as the majority of the nitrogen used by plants is absorbed in the nitrate form. However, nitrate is highly leachable and readily moves with water through the soil profile. If there is excessive rainfall or over-irrigation, nitrate will be leached below the plant's root zone and may eventually reach groundwater.

Nitrate-nitrogen (NO_3-N) in groundwater may result from point sources such as sewage disposal systems and livestock facilities, non-point sources such as fertilized cropland, parks, golf courses, lawns, and gardens, or naturally occurring sources of nitrogen. Proper site selection for the location of domestic water wells and proper well construction can reduce potential nitrate contamination of drinking water source (World Health Organisation, 1996). The primary health hazard from drinking water with nitrate-nitrogen occurs when nitrate is transformed to nitrite in the digestive system. The nitrite oxidizes iron in the haemoglobin of the red blood cells to form methaemoglobin, which lacks the oxygen-carrying capacity of haemoglobin. This creates the condition known as methaemoglobinaemia (sometimes referred to as "blue baby syndrome"), in which blood lacks the ability to carry sufficient oxygen to the individual body cells causing the veins and skin to appear blue (World Health Organisation, 1996). Most humans over one year of age have the ability to rapidly convert methaemoglobin back to oxyhaemoglobin. However, in infants under six months of age, the enzyme systems for reducing methaemoglobin to oxyhaemoglobin are incompletely developed and methaemoglobinaemia can occur. This also may happen in older individuals who have genetically impaired enzyme systems for metabolizing methaemoglobin. The guideline value of nitrate-nitrogen is 50 mg/L and that of nitrite-nitrogen is 1.0 mg/L (World Health Organisation, 2007).

2.10 Microbiological quality of drinking water

The determination of the microbiological quality of water is essential in testing for the overall quality of water, which often involves the enumeration of bacteria of faecal origin

(Luksamijarulkul, 1994). The contamination of water with infected faecal material is common in areas with poor standards of hygiene and sanitation (Luksamijarulkul *et al.,* 1994). Microbial contamination of drinking water also remains a concern in several regions of Europe. In Central and Eastern Europe and Western Asia, it is estimated that greater than 5% of all childhood deaths are attributable to diarrheal disease, which is often a result of poor-quality drinking water, inadequate sanitation, or improper personal hygiene (Valent *et al*., 2004).

Good quality water is odorless, colorless, tasteless, and free from faecal pollution (Shilklomanov, 2000). Lamentably, a substantial portion of the population of the world, especially in Sub-Saharan Africa, is without water that fits this qualification. This means that a lot of people probably settle for unwholesome water, water that pose a serious health threat by way of water-borne infections. It is for this reason that the need for having potable water is considered a great public health issue.

Securing the microbial safety of drinking-water supplies is based on the use of multiple barriers, from catchment to consumer, to prevent the contamination of drinking water or to reduce contamination to levels not injurious to health. Safety is increased if multiple barriers are in place, including protection of water resources, proper selection and operation of a series of treatment steps and management of distribution systems (piped or otherwise) to maintain and protect treated water quality. The preferred strategy is a management approach that places the primary emphasis on preventing or reducing the entry of pathogens into water sources and reducing reliance on treatment processes for removal of pathogens (WHO, 2004).

2.10.1. Total and Faecal Coliforms

Coliforms are a group of bacteria that can be associated with unhygienic handling of food and water. They are a broad class of bacteria found in the environment, including the faeces of man and other warm-blooded animals. The presence of coliform bacteria in drinking water may indicate a possible presence of harmful disease-causing organisms (DiPaola, 1998). Drinking water must be free of disease-causing organisms. The analysis of drinking water for coliforms is relatively simple, economical, and efficient (http://www.bfhd.wa.gov/info/coliform.php).

Coliform bacteria live in soil or vegetation and in the gastrointestinal tract of animals. Coliforms enter water supplies from the direct disposal of waste into streams or lakes or from runoff from wooded areas, pastures, feedlots, septic tanks, and sewage plants into streams or groundwater. In addition, coliforms can enter an individual house via backflow of water from a contaminated source, carbon filters, or leaking well caps that allow dirt and dead organisms to fall into the water **(**Craun, 1986).

Coliform bacteria are ubiquitous in nature, and many types are harmless. Therefore, it is not definitive that coliform bacteria will cause sickness. Many variables such as the specific type of bacteria present, and your own immune system's effectiveness will determine if you will get sick. In fact, many people become immune to bacteria that are present in their own water **(**Craun, 1986).

Total coliforms and faecal coliforms are types of bacteria that are able to utilize lactose sugar for their growth. Coliforms indicate the presence of pathogens. Total coliform is organisms that exist in the human or from the environment. As a source and occurrence, total coliform bacteria (excluding *E. coli*) occur in both sewage and natural waters. Some of these bacteria are excreted in the faeces of humans and animals, but many coliforms are heterotrophic and able to multiply in water and soil environment. Total coliforms can also survive and grow in water distribution systems, particularly in the presence of biofilms (Craun *et al*., 1997).

Faecal coliform is more tolerant of high temperature that is 40°C and above and are bacteria that are associated with human or animal wastes. They usually live in human or animal intestinal tracts, and their presence in drinking water is a strong indication of recent sewage or animal waste contamination (Food and Drugs Administration, 1995). Detection and identification of these organisms as faecal organisms or presumptive *Escherichia coli* is considered to provide sufficient information to assess the faecal nature of pollution (Geldreich, 1980).

2.10.2. Escherichia coli

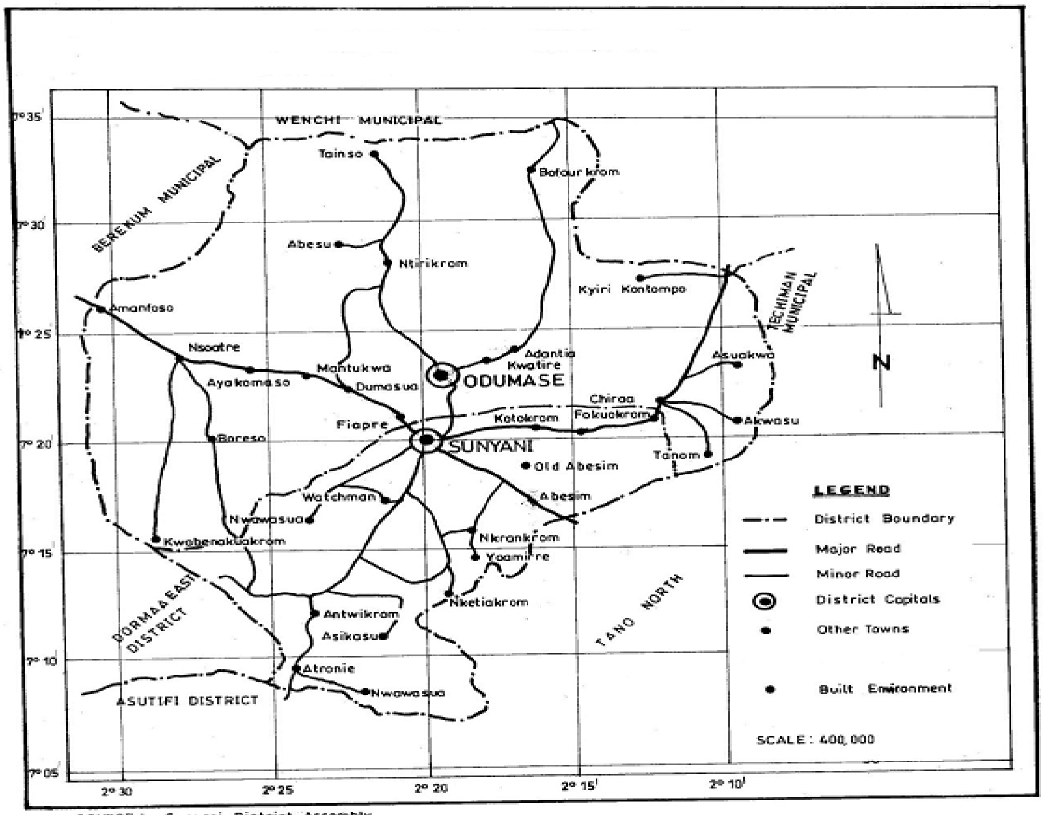
Escherichia coli (*E. coli*) are Gram-negative, non-spore-forming, rod shaped bacteria which are capable of aerobic and facultative anaerobic growth in the presence of bile-salts or other surface-active agents with similar growth-inhibiting properties. They usually ferment lactose at 37 °C within 48 hours, possess the enzyme β-galactosidase and are oxidase-negative (Anon, 1992). *Escherichia coli* is present in very high numbers in human and animal faeces and is rarely found in the absence of faecal pollution, although there is some evidence for growth in tropical soils (Grabow, 1996). The presence of *Escherichia coli*, a faecal coliform in drinking water is a strong indicator of recent sewage or animal waste contamination. Treated water should therefore not contain this organism because it is also an indicator microorganism in drinking water (USEPA, 2003).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Study Area

The study area was the Sunyani Municipality of the Brong-Ahafo Region of Ghana (Figure 1). The Municipality lies between Latitudes 7^{o} 20’N and 7^{o} 05’N and Longitudes 2^{o} 30’W and 2^{o}10’W and shares boundaries with Sunyani West District to the north, Dormaa East District to the west, Asutifi District to the south and Tano North District to the east. The municipality has a total land area of approximately 829 sq. km with a total population of 248,496 people. The Brong-Ahafo Region has over sixty sachet water producers with just about 30% certified producers (GSS, 2010).



SOURCE : Sunyani District Assembly

Figure 1: Map showing the Sunyani Municipal and Sunyani West District Assemblies

3.2. Sampling

3.2.1 Questionnaire

In order to determine the sachet water brands mostly patronized by the inhabitants of the Sunyani municipality, questionnaires were distributed to one hundred and fifty (150) respondents in the municipality. Data was collected on consumer perception of sachet water quality in the municipality. The specific questions asked consumers are summarized in Appendix IV.

In the administration of the questionnaires, respondents' understanding of the questions were limited especially among the uneducated who could neither read nor write. They were then assisted by translating the questions into the local Asante Twi language.

3.2.2 Water Sampling

The study was undertaken for three months, between March and May, 2014. A bag each (each containing 30 sachets) of 6 most patronized brands of sachet water were purchased from manufacturers on the same day. The brands were coded as: SW1, SW2, SW3, SW4, SW5 and SW6. Triplicate of each brand was transported to the Quality Control Laboratory of Ghana Water Company Limited in Sunyani immediately after purchasing for analysis. The remaining packs were stored in a water cage for monthly analysis for a period of three (3) months.

3.3 Physico-chemical analysis

3.3.1 Determination of pH

In the laboratory, pH meter (HACH HQ11d) was used to determine the pH of the water samples. Buffer solutions of pH 4.0, 7.0 and 10.0 were used to calibrate the pH meter.

Procedure:

About 50 ml of water sample was poured into a clean glass beaker and the electrode inserted into it after it had been rinsed with distilled water. The sample was stirred with the electrode to free any bubbles from the electrode area. The read button of the pH meter was turned and the pH was read and recorded. This was repeated three times for all other water samples.

3.3.2 Determination of Apparent Colour

The apparent colour of water samples was determined by HACH Lange Spectrophotometer (model DR-2000) after calibration.

*Procedur*e:

The Spectrophotometer was first zeroed, using distilled water in the 25 ml nessler cell at a wavelength of 45 nm and platinum-cobalt unit of 50 mm. The 25 ml cell was then filled to the mark with water sample and the outside wiped dry with tissue paper to eliminate figure prints and moisture. The cell was inserted into the cell chamber and the lid closed. After 5 minutes the apparent colour was read and recorded in Hazen units.

3.3.3 Determination of Conductivity

WAGTECH Conductivity/ TDS meter was used to determine the conductivity of water samples. *Procedure*:

The meter was calibrated by using standard sodium chloride solution of 12880 μS/cm. The conductivity meter was returned to the operation mode for measurement. About 50 ml of water sample was poured into a clean glass beaker and the conductivity meter electrode was inserted into the water. The value was read and recorded after 5 minutes in μS/cm. The same procedure was repeated three times for all other water samples.

3.3.4 Determination of Turbidity

Turbidity of water samples was determined with JENWAY 6035 TURBIDIMETER.

Procedure:

The turbidity meter was calibrated with Formazin standard solutions of 0.2 NTU, 10 NTU, 100 NTU and 1000 NTU by filling consecutively a clean dry cuvette with the well mixed standard solutions. It was returned to the measurement mode and used. 10 ml cell was filled with distilled water which was used to zero the machine. Another cell was filled with the water sample to be analysed and then covered with light shield cap. The outer surface of the cell was wiped dry with a clean tissue paper. The cell was pushed firmly into the optical well and the lid closed. The NTU value was recorded after the read button was pressed on the machine to give the turbidity value.

3.3.5 Determination of Total Dissolved Solids

A multifunctional HANNA meter (model HI 9032) was used to determine the total dissolved solids of water samples in the laboratory after calibration.

Procedure:

About 50 ml of water sample was poured into a clean glass beaker. The electrode was immersed into the sample and stirred to ensure uniform mixture. After the reading stabilized the value was read and recorded in mg/L.

3.3.6 Determination of Dissolved Oxygen

JENWAY Dissolved Oxygen meter 9300 was used. Measurement was done after the meter has been calibrated according to the manufacturers' instruction.

Procedure:

Using a clean pipette, 50 ml of the water sample was dispensed into a clean glass beaker. The electrode of the DO-meter was immersed into the water sample and stirred to ensure uniform mixture. After the reading stabilized, the value was read and recorded in mg/l.

3.3.7 Determination of Total Alkalinity

Total alkalinity was determined by titrimetric method using 0.02M H2SO4 as titrant, phenolphthalein and methyl orange as indicators.

Procedure:

Using pipette, 50 ml of water sample was measured into a clean conical flask and two drops of phenolphthalein indicator were added. The sample turned pink and was titrated against 0.02M H_2SO_4, swirled gently until the pink colour just disappeared. The titre value (Tv) was read and recorded. If the sample remained colourless after the addition of the phenolphthalein indicator, three drops of methyl orange indicator were added. The yellow sample was then titrated against 0.02M H_2SO_4 swirling gently until the colour changed from yellow to orange and the titre was read and recorded.

Calculation:

$$Total\ Alkalinity(mg/l)\ \frac{A \times T \times 1000}{Sample\ Volume\ (ml)}$$

where

A = Titre of standard acid at phenolphthalein end point

T = Titre of standard acid at methyl orange end point

3.3.8 Determination of Total Hardness

Procedure:

Using a clean pipette, 100 ml of water sample was dispensed into a clean conical flask and 1.0 cm^3 of 4.0 M Ammonium buffer solution (pH = 10.0) and 0.5 cm^3 of Eriochrome Black-T indicator was added to obtain a light pink colour. The content in the conical flask was titrated with 0.02 M EDTA solution (Ethylene Diamine Tetra Acetic acid), mixed gently until the colour changed from light pink to blue. Titration was repeated until a consistent titre was obtained. The average titre value was recorded and total hardness was calculated as:

$$Total\ Hardness\ (mg/l) = \frac{Average\ titre\ \times 10}{Sample\ Volume\ (ml)}$$

3.3.9 Determination of Calcium Hardness and Calcium Ion

Procedure:

Using a clean pipette, 100 ml of the water sample was poured into a clean conical flask. About 1 ml of aqueous solution of 4.0 M NaOH was added to the contents of the flask, followed by the addition of about 0.4g powdered Ammonium murexide indicator. The content in the conical flask was titrated with 0.02 M EDTA (Ethylene Diamine Tetra Acetic acid) solution, mixing gently until the colour changed from pink to purple indicating the endpoint. Titration was repeated until a consistent titre was obtained. The average titre value was read and recorded.

Calculation:

$$Calcium\ Hardness\ as\ CaCo_3(mg/l) = \frac{Average\ Titre\ \times 10}{Sample\ Volume\ (ml)}$$

The concentration of calcium ion was calculated from the same titration as follows:

Ca^{2+} (mg/L) = Calcium hardness × 0.40

(American Public Health Association, 1998).

3.3.10 Determination of Magnesium Hardness and Magnesium Ion

The magnesium hardness was determined as the difference between the total hardness and calcium hardness, i.e.

Magnesium Hardness = [Total hardness] – [Calcium hardness]

The concentration of magnesium ion was obtained from the magnesium hardness as follows:

Mg^{2+} (mg/L) = Magnesium hardness × 0.243 (American Public Health Association, 1998).

3.3.11 Determination of Phosphate

HACH DR 2000 Spectrophotometer was used to determine phosphate after the meter had been calibrated.

Procedure:

A clean test tube was filled with water sample to the 25 ml mark. A tablet of potassium persulfate for phosphanate powder was added, crushed and dissolved. The mixture was allowed to stand for ten minutes for full colour development. One phosver 3 phosphate reagent powder pillow was added to the sample and swirled to mix. The test tube was inserted into the chamber and a wavelength of 890 nm was selected and the sample value read. The value read was multiplied by 0.2 and recorded in mg/L.

3.4 Nutrients Analysis

3.4.1 Determination of Ammonia

HACH DR 2000 Spectrophotometer was used to determine ammonia after the meter had been calibrated.

Procedure:

A clean test tube was filled with water sample to the 25 ml mark. Three drops of mineral stabilizer was added to the sample which was inverted to mix. Three drops of polyvinyl alcohol dispersing agent was also added and inverted to mix. 1.0 ml of nessler reagent was added and inverted to mix. The mixture was allowed to stand for a minute, a yellow colour was developed. The solution was poured into a cell. The cell was inserted into the chamber and a wavelength of 425 nm was selected and the sample value read and recorded in mg/L.

3.4.2 Determination of Nitrite-Nitrogen

The Lovibond Nessleriser (model 2150) was used to measure nitrite-nitrogen by comparator method after the instrument had been calibrated.

*Procedur*e:

Using a clean pipette, 50 ml of the water sample was poured into a clean Erlenmeyer flask and 2 ml each of Griess-Ilosvays No. 1 and 2 were added, swirled and allowed to stand for 15 minutes. If colour changed to pink, a nesseler's tube was filled with the mixture and then inserted into the chamber. The value was read by matching colour using the nitrite disc and comparator.

NB.: The markings on the disc represent the actual amount of nitrogen (N) present as nitrite.

Calculation:

$$N(mg/l) = \frac{Disc\ Reading\ \times 0.5}{Sample\ Volume\ (ml)}$$

NO_2 (mg/L) = N (mg/L) × 3.284 (American Public Health Association, 1998).

3.4.3 Determination of Nitrate-Nitrogen

HACH DR 2000 Spectrophotometer was used to determine Nitrate- Nitrogen after the meter had been calibrated.

Procedure:

A sample cell was filled to the 25 ml mark with the sample. One Nitraver 5 Nitrate reagent powder pillow was added to the sample. The sample was shaken vigorously for a minute and allowed to stand for 5 minutes for an amber colour to develop. The cell was inserted into the chamber and a wavelength of 500 nm was selected and the sample value read and recorded in mg/L.

3.4.4 Determination of Chloride

Argentometric method was to determine chloride concentrations in water samples.

Procedure:

Potassium chromate indicator solution was prepared by dissolving 50 g of K_2CrO_4 in a little distilled water and 1.0 M $AgNO_3$ solution was added until a definite precipitate was formed. The solution was allowed to stand for twelve hours, after which it was filtered and diluted to 1000 ml. The silver nitrate titrant solution (0.0141 M) was prepared by dissolving 2.395 g $AgNO_3$ in distilled water and diluted to 1000 ml.

Using pipette, 50 ml of water sample was poured into a clean conical flask. 1 ml of 5% Potassium chromate (K_2CrO_4) indicator was added to the sample. The sample was titrated against 0.0141M $AgNO_3$ solution, with gentle swirling until the colour changed from yellow to brick red. The titre value was read and recorded in millimeters. The concentration of chloride was calculated as:

$$Cl^-(mg/l) = \frac{(A - 0.2) \times 0.5 \times 100}{Sample\ Volume\ (ml)}$$

Where A = Titre value (American Public Health Association, 1998).

3.5 Bacteriological Quality Analysis

The bacteriological quality of the drinking water samples was assessed by using total coliforms, faecal coliforms and *Escherichia coli* as indicators (American Public Health Association, 1998). Total coliforms, faecal coliforms and *Escherichia coli* was identified using single strength MacConkey broth and tryptone water by the three tube Most Probable Number method.

3.5.1 Preparation of Media

Purple MacConkey broth was prepared by dissolving 35 g of the powder in 1.0 litre of distilled water. It was well mixed and dispensed into fermentation tubes with inverted Durham tubes. The bottles with their contents were autoclaved for 15 minutes at 121^{o}C (American Public Health Association, 1998).

Tryptone water (Buffered) was prepared by dissolving 15 g of the powder in 1.0 litre of distilled water and mixed well. The mixture was distributed into final containers and sterilized by autoclaving for 15 minutes at 121^{o}C.

Kovac’s reagent was prepared by dissolving 5 g of p-dimethylaminobenzaldehyde in 25 ml of alcohol and 25 ml of 1.0 M HCl was added slowly and finally stored at 4^{o}C in the dark.

3.5.2 Total and Faecal coliform Identification and Enumeration

Serial dilutions of 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} were prepared for each water sample using distilled water. One milliliter aliquots from the raw water sample and each set of the dilutions were inoculated into three fermentation tubes containing 5 ml of MacConkey broth with inverted Durham tubes. The tubes were closed firmly, agitated to distribute the sample evenly and inverted gently to expel air from the Durham tubes. The first set of fermentation tubes were incubated at 35^{o}C for 48 hours to determine total coliforms growth and the second set were incubated at 44^{o}C for 24 hours to determine faecal coliforms growth. The tubes that showed colour change, from purple to yellow with gas collected in the Durham tubes after 24 and 48 hours were identified as positive for faecal and total coliforms, respectively, and quantified from the MPN tables as MPN per 100 ml.

3.5.3 Identification and Enumeration of *Escherichia coli*

From each of the presumptive positive tubes identified, 1.0 ml was transferred into 5 ml Tryptone water in a fermentation tube and incubated at 44^{o}C for 24 hours. A drop of Kovac's reagent was then added to the tube of trypton water. All the tubes showing a red ring colour development after gentle agitation indicated the presence of indole and recorded as confirmed for *Escherichia coli* count. Counts of bacteria per 100 ml were calculated from the Most Probable Number (MPN) table.

3.6 Quality Assurance

In order to ensure that the results of analysis obtained were accurate, quality assurance measures were observed as follows:

All the instruments used in the research were calibrated with standards of known concentrations, according to the manufacturer's instruction.

Samples were analysed based on Standard Methods for Examination of Water and Wastewater (American Public Health Association, 1998).

The average value of three triplicate samples was taken for each determination of water quality parameter.

All the glassware was thoroughly cleansed with appropriate detergent and rinsed with distilled water, otherwise autoclaved as in bacteriological quality analysis. Pairs of scissors, automatic pipette, single strength MacConkey broth, tryptone water and distilled water were autoclaved at 121^{o}C for 15 minutes.

The tip of each sample of sachet was disinfected with 70% ethanol before opening and inoculation.

3.7 Statistical Analysis

The research uses SPSS version 16.0 and Microsoft Excel 2013 for analysing the data collected. Descriptive statistics, statistically significant tests and graphs are used in the presentation and analysis of the data. All statistical tests were performed at 95% confidence level.

3.8 Ethical Consideration

Since permission or consent of the sachet water producers was not sought, the identities of the various brands were hidden, and instead codes were used instead of the brand names.

CHAPTER FOUR

RESULTS

4.1 Physical and Chemical characteristics of packaged Water

This section presents physical and chemical parameters that were selected to assess the quality of most patronized sachet water sold in Sunyani. The parameters include pH, apparent colour, conductivity, turbidity, total dissolved solids (TDS), dissolved oxygen (DO), alkalinity, total hardness, calcium hardness, magnesium hardness, calcium, iron, magnesium and phosphate.

Table 2 shows that the pH of the water samples ranged from 6.6 to 7.7±0.1 in SW1 and SW4, respectively, and were within the range (6.5 - 8.5) recommended by the WHO (2011) and Ghana Standards Board (1998) for drinking water. No significant variations were observed during the months of study ($p = 0.946$). However, pH varied significantly within the brands ($p < 0.05$).

Apparent colour in all brands of sachet water studied ranged from 4.0±1.0 to 5.7±1.5 Pt.Co (Table 2). The values were within the WHO and GSA standards.

For conductivity, all the mean values were within the WHO guideline limit as well as the GSA standards for drinking water, with SW4 and SW2 recording the lowest (36.9±0.2 µS/cm) and highest (247.0±6.1 µS/cm) conductivity values, respectively (Table 2). Within each brand, conductivity did not vary significantly during the months ($p = 0.996$), but varied significantly among the different brands ($p < 0.05$).

Table 2 shows that average turbidity values in the select brands of sachet water in the Sunyani Metropolis were low (0.9±0.2 to 1.4±0.4 NTU) and were within the 5 NTU recommended by the WHO and GSA for drinking water. However, only two of the brands (i.e. SW3 n and SW4) were within the recommended 1 NTU for packaged water.

Total Dissolved Solids (TDS) ranged from 18.9±0.6 mg/l observed in the SW4 to 136.8±1.5 mg/l observed in SW3 (Table 2). All the values were within the acceptable limit of 1000 mg/l for drinking water by the WHO (2007).

Levels of dissolved oxygen (DO) were generally low and ranged between 2.8±0.0 and 3.6±0.1mg/l in the brands (Table 2).

SW1, SW2, SW5 and SW6 recorded low alkalinity values (< 50 mg/l) whereas SW3 and SW4 recorded medium alkalinity (Table 2). The analysis of the results on alkalinity shows that there were no significant differences within the months ($p = 0.779$). There were, however, significant differences within the six brands ($p = 0.0045$).

The average values for total hardness varied across the brands, ranging from 25.0±1.2 mg/l in SW4 to 80.0±0.6 mg/l in SW3. Similarly, calcium hardness varied from 20 mg/l in SW4 to 68.3±0.6 mg/l in SW5. Again, SW4 recorded the lowest magnesium hardness (7.0±1.7 mg/l). All the concentrations observed were within the WHO (2007) guideline value of 500 mg/l for packaged water.

Table 2: Means and standard deviations of physico-chemical parameters of selected sachet water brands in Sunyani

Parameter	SW1	SW2	SW3	SW4	SW5	**SW6**	WHO (2007) / GSA (1998)
pH	6.6±0.0	6.6±0.1	6.7±0.1	7.7±0.1	6.6±0.1	6.5±0.0	6.5 - 8.5
Apparent colour (Pt. Co)	5.7±1.5	5.0±1.0	4.0±1.0	4.0±1.0	4.0±1.0	5.0±1.0	0-15
Conductivity (µS/cm)	126.3±2.1	247.0±6.1	273.0±2.6	36.9±0.2	62.7±1.4	189.1±1.9	150000
Turbidity (NTU)	1.4±0.4	1.2±0.1	1.0±0.2	0.9±0.2	1.1±0.2	1.1±0.1	5
TDS (mg/l)	63.6±1.0	122.8±2.3	136.8±1.5	18.9±0.6	31.1±0.4	94.5±0.9	1000
DO (mg/l)	3.1±0.1	3.0±0.1	2.8±0.1	2.8±0.0	3.6±0.1	2.9±0.1	-
Alkalinity (mg/l)	31.3±0.6	47.7±1.2	56.7±1.2	51.7±14.4	46.3±0.6	45.3±0.6	-
Total hardness (mg/l)	40.0±0.0	75.0±34.6	80.0±0.6	25.0±1.2	72.0±0.0	75.0±0.6	500
Ca hardness (mg/l)	32.0±0.0	60.0±0.0	61.3±0.6	20.0±0.0	68.3±0.6	65.0±0.0	-
Mg hardness (mg/l)	11.2±2.8	21.0±5.2	22.3±3.7	7.0±1.7	19.1±14.2	20.7±9.2	500

4.2 Levels of Nutrients in Sachet Water

The different brands of packaged water were tested for levels of concentrations of calcium, magnesium, phosphate, ammonia, chloride as well as nitrate and nitrite ions in the samples. The results are presented in Table 3 below. Phosphate levels were low in all the samples with an overall average of 0.06 mg/l. Calcium ion concentrations ranged between 7.0 and 18.0 mg/l with magnesium ions also ranging between 0.89 and 2.43 mg/l.

Ammonia concentrations ranged from 0.2 mg/l observed in SW1 and SW6, to 0.9 mg/l in SW4 (Table 3). The concentrations of ammonia in most of the brands were below the Ghana Standards Board (1998) and WHO (2007) permissible limit of 1.5 mg/l.

The nitrite-nitrogen and nitrate-nitrogen contained in the packaged water samples were generally low, with mean values ranging from 0.01 to 0.15 mg/l and 2.37 to 8.87 mg/l, respectively (Table 3). The values obtained were all below the WHO acceptable limit of 50 mg/l. No significant difference was recorded during the storage period of 3 months (p = 0.991). For the different brands, however, the differences observed were significantly different (p = 1.26E-16).

For chloride ions in the water samples, mean levels ranged from 23.67 to 58.33 mg/l. All the values were all within the acceptable range of 250 mg/l by the WHO (2007) and GSA standards.

Table 3: Means and standard deviations of concentrations of ions in select brand of sachet water in Sunyani

Ion	Brand of Sachet water						WHO (2007) / GSA (1998)
	SW1	**SW2**	**SW3**	**SW4**	**SW5**	**SW6**	
Ammonia (mg/l)	0.2±0.2	0.3±0.4	0.3±0.4	0.9±0.0	0.6±0.1	0.2±0.0	1.5
Phosphate (mg/l)	0.03±0.01	0.04±0.01	0.08±0.01	0.10±0.0	0.02±0.01	0.08±0.01	0.3
Nitrite (mg/l)	0.01±0.0	0.02±0.01	0.01±0.0	0.13±0.03	0.04±0.02	0.15±0.06	1
Nitrate (mg/l)	2.71±0.06	2.37±0.15	2.67±0.03	4.57±0.15	4.30±0.10	8.87±0.06	50
Chloride (mg/l)	26.57±19.8	55.33±1.15	58.33±1.15	23.67±3.21	28.33±1.15	50.67±0.58	250
Calcium (mg/l)	9.6±2.80	18.0±5.2	20.27±3.93	7.0±1.0	11.87±13.63	15.67±8.96	-
Magnesium (mg/l)	1.94±0.0	3.64±0.0	4.37±0.0	1.46±0.25	0.89±0.14	2.51±0.14	-

4.3 Bacteriological Quality of the Water Samples

All the brands recorded 0 MPN/100 ml except SW6 which recorded 9.1 MPN/100 ml. Again, none of the brands recorded faecal coliforms and *E.coli*.

4.4 Consumers' Perception of Water Quality

The results obtained after administering questionnaires to hundred and fifty respondents to determine the consumers' perception of sachet water quality are presented in this section.

4.4.1 Demographics

Respondents who took part in the exercise were aged 15 years and above. They were made of 61 (40.7 %) males and 89 (59.3%) females.

In order to have people who drink sachet water as respondents, they were asked whether or not they consume sachet water. Respondents who said they drank sachet water always were 101 (67.33%), 32 (21.33%) sometimes drank sachet water while the rest, 17 (11.33%) rarely drank sachet water.

4.4.2 Brand of Sachet Water Preferred by Respondents

Of the 150 respondents, majority (32 people or 21.3%) preferred SW2, followed by SW1 (28 or 18.7%), SW3 (18 or 12%), SW6 (13 or 8.67%), SW4 (9 or 6%), and SW5 (6 4%), in that order. Forty-four persons (or 29.3% of respondents) preferred other brands.

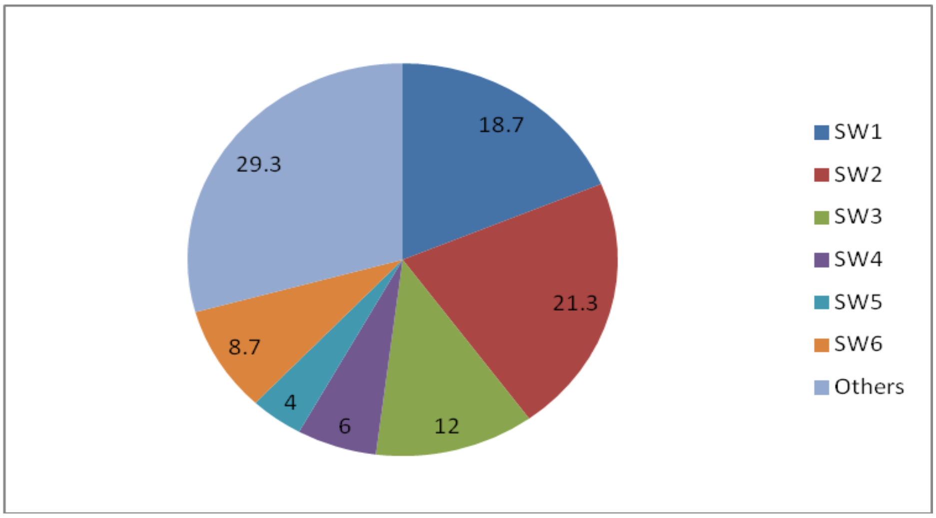


Figure 2: Consumers' preference for sachet water brands in Sunyani

Consumers' choice of a particular brand was influenced by several factors which included quality of the water (30.7%), taste of the water (25%), knowledge of the source of the water for production (21.3%). Others cited reasons such as readily availability of the product (14.6%) and packaging (8%) as the main factors that influenced their choice of sachet water.

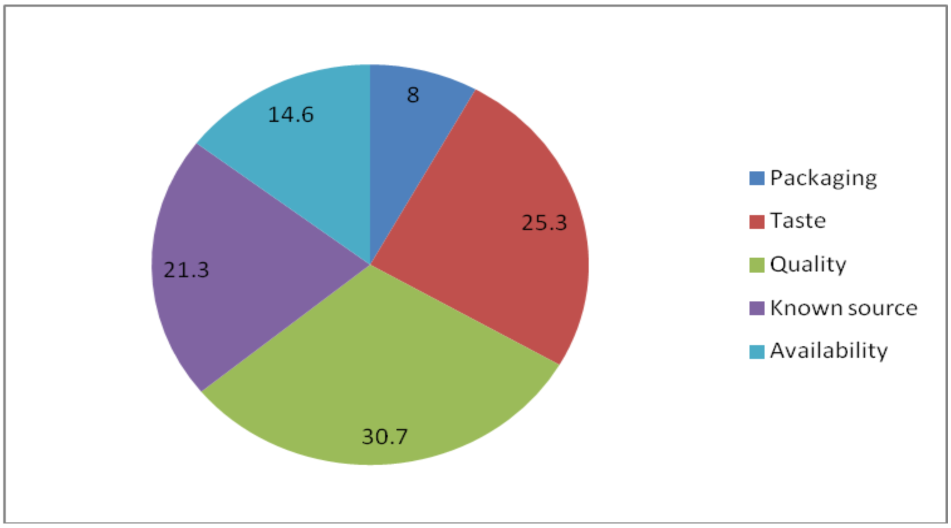


Figure 3: Factors influencing consumers' choice of sachet water

Also, 67 people (44.7%) reported having encountered problems with some sachet water brands while 83 (55.33%) reported otherwise. Thirty-seven people (55.2%) reported bad taste, 7 (10.5%) reported change in colour, 18 (26.9%) reported presence of particles in the water and 5 (7.5%) reported fading of the label.

CHAPTER FIVE

DISCUSSION

5.1 Physico-chemical parameters

The pH is one of the most important determinants of water quality. International standards for drinking water suggest that pH less than 6.5 or greater than 8.5 would impair the portability of the water. The standard limit of the pH of water used in this research is between 6.5 - 8.5 (WHO, 2007; Ghana Standards Board, 1998). All the brands considered and tested in the Sunyani Metropolis had pH values that were within the specified range. Even though differences in the pH values varied significantly within the brands, they were not significantly within the months of observation.

Colour in water systems may be as a result of the precipitation of soluble iron or manganese when they react with dissolved oxygen, chlorine disinfectant, and other oxidizing agents during water treatment (WHO, 1984). Drinking water, especially purified drinking water should ideally have no visible colour (WHO, 2007; GSA, 1998). In natural water, colour in water is usually due to the presence of coloured organic matter associated with the humus fraction of soil, aquatic plants, organic matter such as humus, peat or decaying plant matter (Putz, 2003). It may also result from the contamination of the water source, in this case from the manufacturing sites in terms of how the product is packaged and conditions under which this is done. All the sachet water brands studied showed apparent colour of less than 15 Pt Co. Most consumers can detect colour above 15 Pt Co in a glass of water or non-coloured bottled containers. However, about 10% of respondents reported change in colour of some of the brands. Nonetheless, the results indicate that the water may be acceptable to most consumers (WHO, 2007). High colour could also indicate a high propensity to produce by-products from disinfected process.

Conductivity refers to a measurement of the ability of water to conduct electricity (APHA, 1992). Mean conductivity values recorded in the water samples were generally low (36.9-273 μS/cm) and were within the guideline value set by the WHO (2007) for drinking water. The low conductivity values indicate that contaminations due to ions are low and should not affect taste of the water. This probably was the reason why only one-fourth (25%) of respondents considered taste of water an important criterion for choosing a particular brand of water sold in the municipality.

Water may taste salty when the conductivity is as high as 150 mS/m and would fail to quench thirst of consumers when the conductivity is higher than 300 mS/m. Sensitive groups are children under the age of one, people on salt-restricted diets, such as heart and kidney patients and individuals with chronic diarrhoea.

Turbidity is the amount of cloudiness or haziness in water caused by large number of individual particles that are generally invisible to the naked eye, similar to smoke in air. Clarity of water is important in producing products destined for human consumption and manufacturing uses (Martin *et al.*, 2008). Turbidity in water is often caused by suspended matter such as clay, silts, finely divided organic and inorganic matter, soluble coloured organic compounds, plankton and other microscopic organisms. According to WHO, appearance of water with a turbidity of less than 5 NTU is usually acceptable to consumers. Bottled water standards (assumed to be the same for packaged water) recommend a turbidity of less than 1 NTU for the finished product. Turbidity values in the selected brands of sachet water in the Sunyani Metropolis ranged between 0.9±0.2 to 1.4±0.4 NTU, somehow exceeding the 1 NTU guideline value for bottled water. Nevertheless, all the products can be said to be of good turbidity since the values were less than 5 NTU. Turbidity in the packaged water may have been caused by particulate matter that may be present from the source of the water as a consequence of inadequate filtration, presence of inorganic particulate matter in some groundwater or bacteria in the packaging material (Zvikomborero, 2005).

A similar survey conducted in the Ashanti Region by Arkoli (2010), also showed a turbidity range of 0.21 to 1.30 NTU for some selected brands of sachet water.

TDS, which constitutes all the dissolved solids in the water, ranged from 18.9±0.6 to 136.8±1.5 mg/l. TDS gives an indication of whether or not all suspended solids were removed when the source water passed through a fine filter during water treatment processes. Though the TDS concentrations recorded were far below the Ghana Standards Board (1998) and the World Health Organization (2007) permissible limit of 1,000 mg/l, the highly measurable TDS in some of the water samples could be as a result of inadequate filtration by the production companies. Nonetheless, the relatively low TDS recorded indicate that they are soft drinking waters.

Increment in TDS values was also observed as the months of storage progressed. This may be attributable to salt concentration from the basement formation from where the water comes. Although the acceptable limits may vary according to circumstances (Putz, 2003), the presence of high levels of TDS in water may be objectionable to consumers owing to resulting taste and excessive scaling in water pipes, heaters, boilers and household appliances.

Dissolved oxygen in drinking water adds taste and it is a highly variable factor in water (Ramachandra and Solanki, 2006). Although the World Health Organization (2007), and the Ghana Standards Board (1998), have not set any permissible limit for dissolved oxygen concentration in drinking water, brands could be classified as fairly good according to the classification by Ramachandra and Solanki (2006). Low levels of dissolved oxygen in water could indicate high levels of microbiological activity (World Health Organization, 2007). No significant difference was recorded during the 3 months analysis, implying that the storage period had no effect on the dissolved oxygen.

Alkalinity is not considered detrimental to humans but is generally associated with high pH values, water hardness and excess dissolved solids (World Health Organisation, 2006). High alkalinity waters may also have a distinctly flat, unpleasant taste (WHO, 2006). Alkalinity comes from rocks and soils, salts and certain plants activities. If an area's geology contains large quantities of calcium carbonate ($CaCO_3$, limestone), water bodies tend to be more alkaline. SW1, SW2, SW5 and SW6 recorded low alkalinity values (< 50 mg/l) whereas SW3 and SW4 recorded medium Alkalinity (50-250 mg/L as $CaCO_3$). Significant differences were observed within the six brands with a p-value of 0.0045 at 5% level of significance and this may be due to different production methods.

Total hardness in the sampled water varied from one brand to the other. All the values (25.0±1.2 mg/l in SW4 to 80.0±0.6 mg/l in SW3) were less than the maximum allowable limit of 500 mg/l recommended by the WHO. Again, all the brands recorded total hardness values less than 100 mg/l; hence, the water can be described as soft drinking waters. Waters with hardness less than 100 mg/l have a little buffering capacity and may cause corrosion of metallic receptacles (WHO, 2006). Thus, these brands of packaged water have a great potential to contain higher concentration of toxic metals. Very soft waters may also have an adverse effect on mineral balance (WHO, 2006).

Similarly, calcium hardness varied from 20 mg/l in SW4 to 68.3±0.6 mg/l in SW5. Again, SW4 recorded the lowest magnesium hardness (7.0±1.7 mg/l). All the concentrations observed were within the WHO (2007) guideline value of 500 mg/l for packaged water. **S**ignificant differences of 0.002771 and 1.73E-21 were recorded within the brands for total hardness and calcium hardness, respectively. The hardness in drinking water varies depending on the rocks and soils of the area that the water comes from and the treatment process used. These packaged water brands studied come from different areas around Brong-Ahafo Region, and that may have explained the differences in total hardness in the brands.

5.2 Levels in Nutrients

Ammonia concentrations in the sachet water studied ranged from 0.2 to 0.9 mg/L, and were clearly within the 1.5 mg/L recommended by the WHO (2007) in drinking water. The presence of ammonia in all the different products studied may be attributed to disinfection with chloramines (World Health Organization, 2003). The presence of ammonia at higher concentrations is an important indicator of faecal pollution (World Health Organisation, 2003). Taste and odour problems as well as decreased disinfection efficiency are to be anticipated if drinking water contains more than 0.2 mg/l of ammonia.

Calcium ion concentrations ranged between 7.0 and 18.0 mg/l with magnesium ions also ranging between 0.89 and 2.43 mg/l. The levels of both ions were low.

The results of the study showed that nitrite-nitrogen and nitrate-nitrogen were present in all the samples studied. However, their levels were low, meeting the WHO recommended guideline values of 1.0 and 50 mg/L respectively for these ions. According to the World Health Organisation (2004), nitrate and its conversion products may enter drinking water sources from the excessive application of fertilizers, leaching of wastewater and other organic wastes. High nitrite concentrations in drinking water may cause methaemoglobinaemia (NHMRC– ARMCANZ, 1996). This is especially a predicament for newly born infants with other complicating conditions. No significant difference was recorded during the storage period of three months with a p-value of 0.991. For the different brands, however, the differences observed were significant with a p-value of 1.26E-16 and this may be due to different sources of water used for production.

Sources of nitrates may include human and animal wastes, industrial pollutants and non-point source, runoff from heavily fertilized croplands and lawns. High levels of nitrates in drinking water have been linked to serious illness and even death in infants

Chloride is invariably present in small amounts in almost all natural waters and its contents go up appreciably with increasing salinity. High concentration of chlorides is considered to be indicator of pollution due to organic wastes of animal or industrial origin. The chloride concentration of the water samples (23.67 to 58.33 mg/L) were all within the acceptable range of 250 mg/L (WHO, 2007). No significant difference was observed in the chloride concentrations during the storage period of 3 months. Chloride has no adverse health impact, but excess of it impacts bad taste to the drinking water (Putz, 2003).

5.3 Bacteriological Quality of the Water Samples

Microbiological examination of water is used to determine sanitary quality. The various methods that are employed are intended to indicate the degree of contamination with waste (Harley and Prescott, 1990). Sources of water used by some Ghanaians have been shown to be contaminated not only with microbial indicators of faecal pollution, but they also had varied metal and pH levels and these pose a risk to the health of consumers (Obiri-Danso *et al.*, 2002; Obiri-Danso *et al.*, 2004;; Edoh *et al*., 2004; Kyei- Bafour *et al*., 2005).

Coliforms are a group of bacteria that can be associated with unhygienic handling of food and water. The presence of coliform bacteria in drinking water may indicate a possible presence of harmful disease-causing organisms. As per WHO acceptable limit for coliforms of 0 MPN/100 ml of water, all the brands recorded 0 MPN/100 ml with the exception of SW6 which recorded 16 and 2.2 MPN/100 ml for the first and second months, respectively. Bacteriological contamination of sachet water could be attributed to inadequate treatment of water samples by the producers, improper use of filters, poor sanitary conditions and post-production contamination (Addo *et al*., 2009).

The presence of *Escherichia coli*, a faecal coliform in drinking water is a strong indicator of recent sewage or animal waste contamination. Treated water should therefore not contain this organism because it is also an indicator microorganism in drinking water (USEPA, 2003). None of the brands contained *E. coli* which conforms to the WHO acceptable limit of 0 MPN/100 ml.

5.4 Consumers' Perception of Water Quality

One hundred and fifty (150) respondents were selected randomly to answer questionnaires. Out of the 150 respondents, males formed 40.7% and females formed 59.3%. Age of respondents was widely distributed to as ranging from below 20 years to above 51 years. Both genders were involved and varied age distribution because each person takes water and with various sachet water companies emerging each person had a preference.

Out of the questionnaires we were able to identify the six most patronised brands of sachet water in the Sunyani Metropolis. The most patronised sachet water is SW2, followed by SW1. SW3, SW6, SW4 and SW5, respectively.

Majority of the respondents preferred a particular brand because of the quality of the water. Their quality perception was based on recommendation from friends and family. Others preferred their brands because of taste of the water while others were due to the fact that they knew the source of the water for the production of the sachet water. Others cited reasons such as readily availability of the product and packaging as the main factors that influenced their choice of sachet water.

Nearly 45% of the respondents reported having encountered problems with some sachet water brands while over half of respondents (55%) reported otherwise. Among the complaints were bad taste (55%), change in water colour (10%), presence of particles in the water (26%) and 5 fading of the label on the products ((8%). These can be attributed to long storage periods, poor storage condition and poor processing procedure of some of sachet water producing companies. These probably affected consumers' choice of sachet water. These findings are consistent with a study by Mohammed (2012) in investigating customer perception on the quality of water at Adum, a suburb of Kumasi, Ghana, established that respondents' perception of the water taste, smell and colour affected their choice of water for drinking.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

This study found that six (6) of the sachet water products sold in the Sunyani municipality were preferred by majority of respondents. Factors which influenced consumers' choice for a particular brand of sachet water product included good taste, quality of the water, knowledge of the source of the water for production, readily availability of the product and the way the products are packaged.

The study further revealed that the brands of sachet water studied in the metropolis met the Ghana Standards Board (1998) and World Health Organization (2007) guideline for the nutrient, bacteriological, physical and the chemical characteristics of drinking water though SW6 failed to meet the requirements in terms of the bacteriological quality. Thus, in general the brands of sachet water studied are wholesome for human consumption.

6.2 Recommendations

It is recommended that producers of factory-bagged drinking water in Ghana should improve upon their production operations, especially in terms of hygiene, and to ensure strict compliance with guidelines as set by Ghana standard regulatory body;

- That Food and Drugs Board of Ghana monitors all producers and publish on a regular basis the list of producers, who have registered their products.
- Ghana Standard Board (GSB) should make sure that vendors and distributors have the products stored properly.
- Food and Drugs Authority should conduct tests on these products and alert consumers about those which are unwholesome products. There should be information on the

quality of brands of sachet water on sale in the Sunyani metropolis and this should be made available to the consumer population.

- There should be effective awareness campaign amongst the producers to avoid contamination resulting from human activities.
- Further studies should be conducted on the least patronized brands in the municipilty since they may be produced on the blind side of regulatory authorities.

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APPENDICES

APPENDIX I: RAW DATA OF RESULTS FOR THREE MONTHS

ANNEX I: DATA FOR FIRST MONTH

	UNITS	SW1	SW2	SW3	SW4	SW5	SW6
PHYSICO - CHEMICAL ANALYSIS							
PH		6.6	6.7	6.8	7.7	6.7	6.5
APPARENT COLOUR	Pt. Co	4	4	3	3	3	4
CONDUCTIVITY	µs/cm	124	240	270	36.6	61.2	186.9
TURBIDITY	NTU	1	1.1	0.8	0.7	0.9	1.1
TOTAL DISSOLVED SOLID	mg/l	62.4	120.1	135.2	18.8	30.7	93.5
DISSOLVED OXYGEN	mg/l	3.2	3.1	2.9	2.8	3.7	2.9
ALKALINITY	mg/l	31	49	58	35	47	45
TOTAL HARDNESS	mg/l	40	75	80	25	72	75
CALCIUM HARDNESS	mg/l	32	60	62	20	69	65
MAGNESIUM HARDNESS	mg/l	8	15	18	5	3	10
CALCIUM ION	mg/l	12.8	24	24.8	8	27.6	26
MAGNESIUM	mg/l	1.94	3.64	4.37	1.21	0.729	2.43
PHOSPHATE	mg/l	0.02	0.03	0.08	0.1	0.01	0.07
NUTRIENT ANALYSIS							
AMMONIA	mg/l	0.4	0.7	0.8	0.9	0.5	0.2
NITRITE	mg/l	0.006	0.01	0.006	0.1	0.02	0.08
NITRATE	mg/l	2.64	2.2	2.64	4.4	4.2	8.8
CHLORIDE	mg/l	3.7	54	57	20	27	50
BACTERIOLOGICAL QUALITY ANALYSIS							
TOTAL COLIFORM	MPN INDEX	0	0	0	0	0	16
FEACAL COLIFORM	/100ml	0	0	0	0	0	0
E. COLI	/100ml	0	0	0	0	0	0

ANNEX II: DATA FOR SECOND MONTH

	UNITS	SW1	SW2	SW3	SW4	SW5	SW6
PHYSICO - CHEMICAL ANALYSIS							
PH		6.6	6.6	6.7	7.7	6.6	6.5
APPARENT COLOUR	Pt. Co	6	5	4	4	4	5
CONDUCTIVITY	µs/cm	128	250	275	37	63	190.2
TURBIDITY	NTU	1.6	1.2	1	0.9	1.1	1.2
TOTAL DISSOLVED SOLID	mg/l	64.1	124.1	137.1	18.4	31.2	95
DISSOLVED OXYGEN	mg/l	3	2.9	2.7	2.8	3.5	2.8
ALKALINITY	mg/l	31	47	56	60	46	45
TOTAL HARDNESS	mg/l	40	75	79	26	72	75
CALCIUM HARDNESS	mg/l	32	60	61	20	68	65
MAGNESIUM HARDNESS	mg/l	12.8	24	24.4	8	27.2	26
CALCIUM ION	mg/l	8	15	18	6	4	10
MAGNESIUM	mg/l	1.944	3.645	4.374	1.458	0.972	2.43
PHOSPHATE	mg/l	0.03	0.04	0.08	0.1	0.02	0.09
NUTRIENT ANALYSIS							
AMMONIA	mg/l	0.05	0.08	0.09	0.9	0.6	0.2
NITRITE	mg/l	0.008	0.02	0.008	0.15	0.04	0.19
NITRATE	mg/l	2.74	2.4	2.69	4.6	4.3	8.9
CHLORIDE	mg/l	38	56	59	25	29	51
BACTERIOLOGICAL QUALITY ANALYSIS							
TOTAL COLIFORM	MPN INDEX	0	0	0	0	0	2.2
FEACAL COLIFORM	/100ml	0	0	0	0	0	0
E. COLI	/100ml	0	0	0	0	0	0

ANNEX III: DATA FOR THIRD MONTH

	UNITS	SW1	SW2	SW3	SW4	SW5	SW6
PHYSICO - CHEMICAL ANALYSIS							
PH		6.6	6.6	6.6	7.6	6.6	6.5
APPARENT COLOUR	Pt. Co	7	6	5	5	5	6
CONDUCTIVITY	µs/cm	127	251	274	37	64	190.2
TURBIDITY	NTU	1.7	1.3	1.1	1	1.2	1.1
TOTAL DISSOLVED SOLID	mg/l	64.2	124.2	138.1	19.5	31.4	95.1
DISSOLVED OXYGEN	mg/l	3.1	2.9	2.8	2.8	3.6	2.9
ALKALINITY	mg/l	32	47	56	60	46	46
TOTAL HARDNESS	mg/l	40	15	79	27	72	76
CALCIUM HARDNESS	mg/l	32	60	61	20	68	65
MAGNESIUM HARDNESS	mg/l	12.8	24	24.4	8	27.2	26
CALCIUM ION	mg/l	8	15	18	7	4	11
MAGNESIUM	mg/l	1.944	3.645	4.374	1.701	0.972	2.673
PHOSPHATE	mg/l	0.04	0.05	0.09	0.1	0.03	0.09
NUTRIENT ANALYSIS							
AMMONIA	mg/l	0.05	0.08	0.09	0.9	0.6	0.2
NITRITE	mg/l	0.009	0.02	0.009	0.15	0.05	0.19
NITRATE	mg/l	2.74	2.5	2.69	4.7	4.4	8.9
CHLORIDE	mg/l	38	56	59	26	29	51
BACTERIOLOGICAL QUALITY ANALYSIS							
TOTAL COLIFORM	MPN INDEX	0	0	0	0	0	0
FEACAL COLIFORM	/100ml	0	0	0	0	0	0
E. COLI	/100ml	0	0	0	0	0	0

APPENDIX II: ANOVA RESULTS OF PHYSICO – CHEMICAL PARAMETERS

ANNEX I : pH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.837778	5	0.567556	170.2667	1.04E-10	3.105875
Within Groups	0.04	12	0.003333			
Total	2.877778	17				

ANNEX II: APPARENT COLOUR

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.611111	5	1.522222	1.245455	0.347724	3.105875
Within Groups	14.66667	12	1.222222			
Total	22.27778	17				

ANNEX III: CONDUCTIVITY

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	140511	5	28102.19	3120.732	3.02E-18	3.105875
Within Groups	108.06	12	9.005			
Total	140619	17				

ANNEX IV: DISSOLVED OXYGEN

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.397778	5	0.279556	35.94286	8.12E-07	3.105875
Within Groups	0.093333	12	0.007778			
Total	1.491111	17				

ANNEX V: ALKALINITY

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1088.5	5	217.7	6.161321	0.004716	3.105875
Within Groups	424	12	35.33333			
Total	1512.5	17				

ANNEX VI: TOTAL HARDNESS

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7032.944	5	1406.589	7.021242	0.002771	3.105875
Within Groups	2404	12	200.3333			
Total	9436.944	17				

ANNEX VII: CALCIUM HARDNESS

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6018.444	5	1203.689	10833.2	1.73E-21	3.105875
Within Groups	1.333333	12	0.111111			
Total	6019.778	17				

ANNEX VIII: MAGNESIUM HARDNESS

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	585.8511	5	117.1702	2.1183	0.133107	3.105875
Within Groups	663.76	12	55.31333			
Total	1249.611	17				

ANNEX IX: CALCIUM ION

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	391.6	5	78.32	1.482023	0.266426	3.105875
Within Groups	634.16	12	52.84667			
Total	1025.76	17				

ANNEX X: MAGNESIUM ION

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	26.39212	5	5.278424	317.7944	2.58E-12	3.105875
Within Groups	0.199315	12	0.01661			
Total	26.59143	17				

ANNEX XI: PHOSPHATE

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.016761	5	0.003352	43.1	2.95E-07	3.105875
Within Groups	0.000933	12	7.78E-05			
Total	0.017694	17				

APPENDIX III: ANOVA RESULTS OF NUTRIENTS LEVELS

ANNEX I: AMMONIA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.170244	5	0.234049	4.126229	0.020586	3.105875
Within Groups	0.680667	12	0.056722			
Total	1.850911	17				

ANNEX II: NITRITE

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.065955	5	0.013191	15.40407	7.32E-05	3.105875
Within Groups	0.010276	12	0.000856			
Total	0.076231	17				

ANNEX III: NITRATE

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	89.49307	5	17.89861	1673.637	1.26E-16	3.105875
Within Groups	0.128333	12	0.010694			
Total	89.6214	17				

ANNEX IV:

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3800.825	5	760.165	11.21105	0.000345	3.105875
Within Groups	813.66	12	67.805			
Total	4614.485	17				

APPENDIX IV: SAMPLE OF RESEARCH QUESTIONNAIRE

SURVEY QUESTIONNAIRE

CONSUMER PERCEPTION OF SACHET WATER QUALITY.

This questionnaire is for investigating consumer views of most patronised sachet water and quality of sachet water in Sunyani Metropolis.

A. (Please Tick (√) The Correct Answer As Pertaining To You.)

Personal Information

Age: Under 20[ ] 21-30[ ] 31-40[ ] 41-50[ ] 51 and above [ ]

Sex: Male [ ] Female [ ]

3. Highest level of education: Basic school [ ] SHS [ ] University [ ] other tertiary [ ] None [ ]

4. Occupation: ___________________ or None [ ]

B. Packaged Water Consumption

5. Do you drink sachet water?

Almost always [ ] Sometimes [ ] Rarely [ ]

6. Where do you normally drink sachet? Answer:

At Home [ ] In Public [ ] Both at home & in public [ ]

7. Where do you normally purchase sachet water? Answer:

From shops [ ] From vendors by the roadside [ ] At lorry parks and stations [ ] Others [ ]

8. Do you have a specific brand of sachet water you purchase? Yes [ ] No [ ]

If yes, which brand ……………………………..

9. Why do you prefer that brand of sachet water?

Answer: Packaging [ ] Taste Quality [ ] Known source [ ] Readily available [ ]

10. Do you always readily get your preferred choice/brand of sachet water to buy?

Answer: YES [ ] NO [ ]

11. In case of non-availability of your preferred choice at the purchase point, do you purchase any other brand available? Answer: YES [ ] NO [ ]

If yes which brand. ……………………..

12. Have you ever encountered problems with any of the brand(s) of sachet water product(s)? Answer: YES [ ] NO [ ] If yes which brand ………………………….

13. Have you ever experienced any of the following?

I. Presence of impurities/particles in sachet water Yes [ ] No [ ]

II. Presence of bad smell or taste in water Yes [ ] No [ ]

III. Change in colour of packaged water Yes [ ] No [ ]

IV. Faded labels on sachet water Yes [ ] No [ ]

If yes to any of the above, what did you do?

14. If you answered yes to the above, did you report the problem to the employees of the company concerned?

Answer: YES [ ] NO [ ]

15. If you reported the problem, what response did you get and how quick was the response?

………………………………………………………………………………………………..

……………………………………………………………………………………………….

16. Are you aware of any regulatory body or bodies that are responsible for sachet water quality?

Answer: Yes [ ] No [ ]

17. Do you think the regulatory agencies the Ghana Standards Board (GSB) the Food and Drugs

Board (FDB) are doing enough to ensure quality of packaged water products?

Answer: YES [ ] NO [ ]

20. What is your perception of sachet drinking water in terms of its quality?

Excellent [ ] Very good [ ] Good [ ] Fair [ ] Poor [ ]

21. Do you check the following on sachet water brands?

I. Expiry date YES [ ] NO [ ]

II. Ghana Standards Board mark of conformity YES [ ] NO [ ]

III. Address of manufacturer YES [ ] NO [ ]

IV. Mineral content specifications YES [ ] NO [ ]

V. Manufacturing date YES [ ] NO [ ]

VI. Batch Number YES [ ] NO [ ]