KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

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DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

DETERMINATION OF THE PHYSICO-CHEMICAL AND BACTERIOLOGICAL QUALITY OF SACHET WATER PRODUCED IN TUMU, GHANA

By

AYAMBA ABUBAKAR

NOVEMBER, 2015

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

By

AYAMBA ABUBAKAR

PG1470610

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DECLARATION

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

AYAMBA, ABUBAKAR	…………………………	…………………………
(Student ID: PG5752411)	Signature	Date

Certified by:

DR. B. FEI-BAFFOE	…………………………	…………………………
Name of Supervisor	Signature	Date

Certified by:

Dr. I. K. Tetteh	…………………………	………………………
(Head of Department)	Signature	Date

ABSTRACT

This study sought to assess the physico-chemical and bacteriological quality of sachet water produced by three manufacturers coded TWP-A, TWP-B and TWP-C, in Tumu in the Sissala East District of the Upper West Region, Ghana. Three sample points were identified for each manufacturer; producer, wholesaler and vendor. Three samples were analysed for each point per month and replicated over three months. A total of eighty one (81) samples from the three companies were used for the test; nine from each point and twenty seven (27) from each company. Selected physico-chemical parameters (such as TDS, conductivity, colour, turbidity, temperature, sulphate, chloride, nitrate, calcium, magnesium, total hardness were determined by the use of analytical techniques) and bacteriological parameters (including total coliform, faecal coliform and *E. coli*) were tested by the membrane filtration method and pore plate techniques and analysed using ANOVA. With exception of the bacteriological parameters, all the physico-chemical parameters for all three manufacturers were within recommended WHO guideline values and GWCL standard. From the results of the analysis, TWP-A water samples were associated with the most bacterial growth ranging from 0-36 cfu/100 ml total coliforms, 0 - 12.67 cfu/100 ml faecal coliform and 0 - 3.33 cfu/100 ml *E. coli*. TWP-B was next with 0-12.67 cfu/100 ml faecal coliforms growth and 0=3.33 cfu/100 ml *E.coli growth (*Table10). TWP-C water samples were observed to have bacterial growth of 0-0.33 cfu/100 ml faecal coliforms and 0.00 cfu/100 ml *E. coli* (Table 11). TWPC had the highest total coliforms (58.67 cfu/100 ml) for the producer water samples. Generally, this brand was associated with the least bacterial growth of 0.67 cfu/100 ml of faecal coliform, and no *E. coli* growths in all the twenty seven (27) tested samples (Table 12). In all cases, water from the vendor sample points was associated with the most bacteria growth. This was attributed to very low residual treatment chemicals in the water samples, which reduces along the supply chain, causing microbial populations

previously existing as biofilms to soar. Thus, the bacteriological qualities of sachet water from the three brands were high and they could pose a health threat for consumers, especially those who patronise TWP-A sachet water. Generally, all the bacteriological parameters were above the recommended WHO guideline value and GWCL standard of 0.00 cfu/100 ml (Table 1).

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LIST OF ABBREVIATIONS

APH:	Achievement in Public Health
APHA:	American Public Health Association
BPW:	Buffered Peptone Water
CDPHE-WQCD:	Colorado Department of Public Health and Environmental Water Quality Control Division
CFU:	Coliform Forming Units
CHRPE:	Committee on Human Research, Publication and Ethics
E.Coli:	Escherichia Coli
EDTA:	Ethylenediamintetra Acetic Acid-EDTA
EPA:	Environmental Protection Agency
FDA:	Food and Drugs Authority
GSA:	Ghana Standards Authority
GWCL:	Ghana Water Company Limited
IJWREE:	International Journal of Water Resources and Engineering
LMICs:	Low Middle Income Countries
MAC:	Maximum Admissible Concentration
MCL:	Maximum Contaminant Level
MCLG:	Maximum Contaminant Level Goal
MDGs:	Millennium Development Goals
MF:	Membrane Filtration
MOFA:	Ministry of Food and Agriculture
NRCC:	National Research Council of Canada
N/A:	Not Available
NPDWR:	National Primary Drinking Water Regulation
NTU:	Nephelometric Turbidity Units....
P/AQW:	Physical/Aesthetic Quality of Water
PPB:	Parts per Billion
PSW:	Package Sachet Water
PW:	Pure Water
RWN	River Watch Network
SMCLs:	Secondary Maximum Contaminant Levels
TCU:	True Colour Units

TDS:	Total Dissolved Solid
TNTC:	Too Numerous To Count
TTC:	2, 3, 5-Triphenyl Tetra folium Chloride
TVC:	Total Viable Count
TWP-A:	Treated Water Producer A
TWP-B:	Treated Water Producer B
TWP-C:	Treated Water Producer C
UNICEF:	United Nations Children's Fund
US-EPA:	United States Environmental Protection Agency
WHO:	World Health Organization
WRC:	The Water Research Centre

CHAPTER ONE

INTRODUCTION

1.1 Background

Sachet water is one of the most essential commodities for the survival of all lives in Ghana. The importance of sachet water cannot be overemphasised for it helps to provide people with healthy life to be able to carry out economic and developmental activities (UNICEF & WHO, 2004).

Currently, it is of no news that sachet water is the most patronised bagged water for consumption by many people on the Ghanaian markets. Though previous studies have shown that some sachet water companies package their products directly from bore hole, tap and well water sources, it remains the most preferred and patronised by a large section of Ghanaian society FDA (2005). It is widely produced and very common throughout the towns and cities of Ghana and often transported to the hinterlands where access to potable water is not common.

According to Stoler (2012) thirty four point five percent (34.5%) of Ghanaians consumed sachet water as at 2008. Williams, Jalloh, Saquee, Pratt, and Fisher (2004) reports that the scale of “pure” water consumption is substantial: in 2011, documented global sachet water sales exceeded 225 billion litres. While statistics on sales of packaged sachet water (PSW, drinking water packaged in sealed plastic sleeves, typically 500 ml) are very difficult to come by, consumption is increasing rapidly, especially, in LMICs and the world community and individual countries cannot turn a blind eye on its source and quality (Williams *et al.*, 2004).

According to the United Nations Mid-term Assessment Report, UNICEF and WHO (2004), eighty percent (80%) of the world‟s population use an improved drinking water source in 2004, up from seventy one percent (71%) in 1990. Although these numbers indicate the world is on track to meet the goal, there will be challenges as populations increase (IJWREE, 2012). The challenges may range from quantity to quality of factory bagged sachet water right from the production point to the consumer. More especially, with the flooding of the market with sachet water producers and vendors embarking on the best methods to sell their wares, it is incumbent that the quality of water being offered for sale is ascertained as one seeks to satisfy a natural requirement of the human need.

1.2 Problem Statement

Water is a commodity that many take for granted and allows it to be sold on the market provided it is seen to be transparent and packaged in a sachet. But, unhygienic environment coupled with inefficient machines at production points, poor personal hygiene, unclean storage facilities, and bad distribution practices by producers, wholesalers and vendors are all potential causes of sachet water contamination (Mackenzie, 2009).

According to Dibua *et al.* (2007), the potability of water is found uncertain being collected from every available water source with associated contaminants due to lack of adherence to production and analytical standards. Filtration and chemical treatment processes were also eventually built into some of the machines and if they are not service and maintained regularly, sachet water quality could be compromised (Stoler, 2013).

Records from FDA (2005) of Ghana showed that, vended water is considered an unhygienic source of water, the main reason being poor handling and distribution practices. Sachet water vendors sell their products to consumers in all manner of unhygienic conditions, such as, after visiting toilets facilities or having contacts with food and non-food items, after touching animate and inanimate bodies at lorry stations and social gatherings, Lewis and Miller (1997) reports higher levels of potassium in drinking waters through softening using potassium chloride and handling foods that are sources of potassium such as meat and fruits.

Again, the unhygienic conditions under which people store sachet water could also serve as means of its contamination. The deterioration in water quality from source to storage container in the developing world is well-documented Wright, Gundry and Conroy (2004), as are the associated adverse health outcomes. Wholesalers also store sachet water for a long time which may lead to bacteria growth. Sachet water produced in Tumu is mostly transported to its surrounding communities in motor tricycles popularly called “motor kings”, donkey carts and vehicles in largely unhygienic sanitary conditions and could be a source of physico-chemical and bacteriological contamination.

Finally, majority of the people in Tumu are poor, according to MOFA (2010) eighty four percent (84%) of the population live below the poverty line of surviving on less than one dollar a day and patronise sachet water which is relatively cheap. Ghana Statistical Service (2006) showed high sachet water consumption could be linked to the poor. The high consumption of sachet water by larger section of the inhabitants of Tumu has, therefore, necessitated the need to identify the various sources of sachet water contamination in production, distribution and vending processes, for the reason that, information on the levels of bacteriological and physico-chemical quality of factory bagged sachet water will be useful for quality control.

1.3 Justification for the Study

The most important goal of water quality management from health and developmental perspective is to discharge their responsibility and ensure that consumers are not exposed to contaminated sachet water by people engaged in its business.

Since people are in constant dynamic interactions with drinking water for their survival, constant monitoring of sachet water is imperative, Obiri-Danso (2003) reports quality of sachet water sold on Ghanaian markets as being doubtful. Thus, in order to safeguard human development and eliminate unnecessary disease outbreaks that may be caused via physico-chemical and bacteriological contaminations of sachet water, water quality analysis are always ascertained.

1.4 Purpose

The main purpose of the study is to determine the quality of sachet water produced and sold in Tumu & its environs.

1.4.1 Specific Objectives

The specific objectives are to;

1. determine the presence and levels of selected physico-chemical and bacteriological parameters which are relevant to water quality in the water samples from the manufacturers under study.
2. identify differential trends in physico-chemical and bacteriological parameters among the sample points from the producer, through the wholesaler to the vendor for each company..

3. determine whether there are differences in physico-chemical and bacteriological parameters among the three manufacturers (TWP-A, TWP-B and TWP-C) under study or not.

1.4.2 Null Hypothesis

The null hypothesis is conducted on the premises that;

$$\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots = \mu_n$$

α = 0.05 (95% confidence interval)

- **Ho:** no physico-chemical and bacteriological parameters exist in the water samples under study.
- **Ho:** the levels of the selected physico-chemical and bacteriological parameters under study are not different.
- **Ho:** the physico-chemical and bacteriological parameters are the same for all the sample points from the producer, through the wholesaler to the vendor for each manufacturer.
- **Ho:** the physico-chemical and bacteriological parameters among the three manufacturers under study (TWP-A, TWP-B and TWP-C) are not different.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The introduction of sachet water in Ghana was to provide safe, hygienic and affordable instant drinking water to the public to curb the magnitude of water related infections in the country (Ahimah & Ofosu, 2012).

A large section of people living in Tumu and its environs have accepted sachet water as being portable and patronise it for consumption so far as it is colourless, contains no visible debris, produces no odour, and packaged in a transparent sachet. A content of interview drawn from sachet water producers in Tumu on 20th August 2013, revealed that, on the average, about twelve thousand two hundred and forty (12, 240) sachets of water are sold in Tumu and its environs daily. A simple division of the number of sachet water by a population of twelve thousand one hundred and eighteen (12,118) indicates that, at least, a sachet (500 ml) of water is consumed by every resident of Tumu and its environs daily.

As a result of high patronage of sachet water, some producers may not stick to standards in order to meet market demands, though information from the producers indicate constant checks on their standard of production by FDA and GSA. Earlier investigations conducted on the safety of sachet drinking water in Ghana have shown that bottled water on the Ghanaian markets is of good physico-chemical and microbiological quality while the quality of some factory bagged sachet and hand bagged drinking water was noted to be doubtful (Obiri-Danso, 2003).

Reports indicate that Ghanaians accept water in sachet water without questioning its source or purity; they believe that so far as water is bagged in sachet it is free from any impurity which is really not the case (Ahimah & Ofosu, 2012). Obiri-Danso (2003) analysed the quality of bottled water, factory produced and hand tied sachet water sold in Kumasi in the Ashanti region using the membrane filtration method and out of 88 factory produced sachet water sampled, 45% of them showed presence of total coliforms.

2.2 Human Activities that Affect Sachet Water Quality

Various activities of man and natural processes negatively affect the physico-chemical and bacteriological quality of sachet water. Some of these may include picking with hands or packaging with contaminated pathogenic organisms, trace of metals, human produced and toxic chemicals; the introduction of non-native species; the changes in acidity, temperature, and salinity (Felisa, 2014). Research has shown that people bagged sachet water without strict adherence to personal hygiene as related in Obiri-Danso, Okore_Hanson and Jones (2003) states thus; hygiene remained an issue, as bags of sachet water were generally filled by women and children with suspected sanitary practices.

2.3 Water Quality

Water quality is very critical to ensuring that sachet water produced and sold on the Ghanaian market meets WHO guidelines and GWCL standards for consumption. Water meant for drinking has two dimensions that are closely linked to one another and these are; quality and quantity WHO (2006). Water quality is most often defined by its physico-chemical and bacteriological standards Odonkor and Addo (2013), hence, sachet bagged water of good quality maintain international and local water regulatory body‟s standard and guideline limits of stated parameters (*http://www.environment.nsw. gov.au/water/waterqual.htm*).

On the other hand, if quality measurements of drinking water are not kept to recommended standards at factory, wholesale and vendor levels, consumers risk drinking contaminated sachet water which may have negative impact on their lives and people employed in the sachet water business industry could lose their jobs, Stoler (2013). It is in view of the relevant contribution of water quality regulation to ensuring safe drinking water that has informed international regulatory bodies such as WHO to modify water quality standards in line with modern trends of developmental activities such as farming, mining and construction where chemicals and micro-organisms are used and may serve as possible sources of sachet water contamination McGauhey (1968), Obiri-Danso (2003) found forty five percent (45%) out of 88 factory produced sachet water containing total coliform in Kumasi.

2.4 General Characteristics of Water

Water quality can be determined within the limits of physical, chemical and microbiological properties. These water quality characteristics throughout the world are characterized with wide variability. Therefore, the quality of natural water sources used for different purposes should be established in terms of the specific water-quality parameters that affect the possible use of water. Thus, the aim of this section is to provide an overview of water quality based on its physical, chemical, and biological characteristics.

2.4.1 Some Physical and Chemical Properties of Water

Generally, the WHO Guideline values set for some of the physical and chemical parameters of drinking water are not mandatory because they do not have harmful effect on people except in extreme cases, but affect the aesthetic quality of drinking water. These include colour, odour, taste, turbidity, chloride, iron, sodium, manganese, sulphate, zinc, conductivity, calcium, potassium, magnesium, and boron (Gray, 1999).

2.4.2 Biological Indicators of Water Quality

The recognition that faecal polluted water is responsible for spreading enteric disease led to the development of sensitive methods of verifying that drinking water is free from faecal contamination (Anon, 1984). Even though many water-borne pathogens can now be detected, the methods are often difficult and expensive to use (Geldreich, 1978).

2.5 Quality Requirements for Drinking Water-Ghana Standards

The GWCL Standards for drinking water as contained in the GSA (1998) 175 Part 1:1998 indicate the required physical, chemical, and microbial properties of drinking water in Ghana. The standards are adapted from the WHO (1993) standards for Drinking Water Quality but also incorporated national standards that are specific to the country‟s environment, as listed in (Table 1). The word “standards” is used to refer to legally enforceable threshold values for the water parameters analysed, while “guidelines” refer to threshold values and do not have any regulatory status (WHO, 1993).

Table 1: Guideline values with GWCL and US EPA standards for drinking water quality (WHO, 1993).

PARAMETER	UNIT	WHO GV	GWCL STANDARD	US EPA
TDS	mg/l	0-1000	0-1000	0-500
Colour(apparent)	Hz	0-15	0-15	0-15
Turbidity	NTU	0-5	0-5	0-5
Conductivity	µS/cm	-	-	-
Tot. Alkalinity	mg/l	-	-	-
Tot. Hardness	mg/l	0-500	0-500	0-500
Mag. Hardness	mg/l	-	-	-
Phosphate(PO_4^{3-})	mg/l	-	-	-
Silica(SiO_2)	mg/l	-	-	-
Sulphate(SO_4^{2-})	mg/l	0-400	0-400	0-250
Calcium	mg/l	0-200	-	0-200
Nitrate(NO_3^-–N)	mg/l	0-10	0-10	0-10
Chloride	mg/l	0-250	0-600	0-250
Magnesium	mg/l	0-150	-	-
Potassium	mg/l	0-30	-	-
Sodium	mg/l	0-200	-	-

Bicarbonate	mg/l	-	-	-
pH	pH-unit	6.5-8.5	0-10	-
Fluoride	mg/l	0-1.5	0-1.5	0-1.5
Total Coliform	l/100ml	0	-	0
Faecal Coliform	l/100ml	0	-	0

Source: (WHO, 1993) and (US EPA, 2006)

2.5.1 Total Dissolved Solids (TDS)

TDS is the sum of all materials dissolved in water. The presence of solids is partially responsible for both the apparent colour and taste to the water. TDS may also be inorganic in nature and may be responsible for high conductivity values of the water (WSDE, 1991). Measuring TDS give a very good indication of the suitability of a water source for domestic use. High TDS values make the water salty and less palatable compared with moderate mineral content. TDS can harbour bacteria in water and enhance their growth. Research has also shown that a TDS concentration over the

WHO limit of 1000 mg/l can cause gastrointestinal problems in humans and animals. TDS is measured by the use of TDS-meter in mg/l (Environmental Control & Public Health, 1992).

2.5.2 Conductivity

Conductivity is the ability of water to conduct electricity. Water conducts electricity because it contains dissolved solid that carry electrical charges (Perlman, 2014). For example, while sodium, magnesium, and calcium are all cations, their presence indirectly indicates the amount of TDS in the water. Conductivity is an important factor that can indicate a source of pollution that has entered a particular water body (AWWA & APHA, 1998). Conductivity can be affected by many factors. Examples include addition of fresh water, diluting mineral concentration, temperature; the warmer the water, the higher the conductivity and lastly, coastal streams or estuaries, salt water often mixed with fresh water (SWRCB, 2002). The additions of salt to drinking water greatly increase conductivity. According to California State Water Resources Control Board (SWRCB), typical conductivity ranges are: distilled water 0.5 to 3.0 µs/cm, melted snow 2 to 42 µs/cm, drinking water 30 to 1500 µs/cm and fresh streams 100 to 200 µs/cm. Though, no GWCL guideline values are provided, the WHO standard for conductivity is 300 µs/cm.

2.5.3 Colour

Sachet water generally is supposed to be colourless, odourless, and tasteless among other physical properties whilst maintaining pH at 7 pH-units. Even though colour change may not necessarily mean water is contaminated, yet, it could be an indication of change in levels of other parameters. Dissolved organic material from decaying vegetation and certain inorganic matter can cause colour in water APHA (1998). Tristimulus colorimeter is an instrument used to measure colour of water. Although colour itself is not usually objectionable from a health standpoint, its presence is aesthetically objectionable and suggests that the water needs appropriate treatment. The WHO guideline value and GWCL standard for colour of drinking water is ranged from 0-15 Hz (UNICEF, 2003).

2.5.4 Turbidity

The presence of suspended material such as clay, silt, finely divided organic material, plankton, and other particulate material in water caused turbidity. These particles may harbour microbiological contaminants that are harmful to human health or that decrease the effectiveness of disinfectants. Excessive blooms of algae, especially the blue-green algae or the growth of aquatic microorganisms can be trapped in inorganic material in water and impart foul taste and odours Mackenzie(2009), and this may depend on the sanitary conditions administered at the production, wholesale and vending level. Turbidity can be measured by the use of turbid meter with its units expressed as Nephelometric Turbidity Units (NTU) or turbidity units (Shelton & Sibilia, 2005).

2.5.6 Temperature

Temperature has correlation with conductivity of drinking water; an increase in temperature causes potassium, sodium and phosphate to ionize enhancing conductivity level of water. Temperature impacts on chemical and biological characteristics of sachet water; it affects the dissolved oxygen level in the water, photosynthesis of aquatic plants, metabolic rates of aquatic organisms, and the sensitivity of these organisms to pollution, parasites and diseases(Pangborn & Bertolero, 1972). Temperature in Degree Celsius (^{o}C) or Fahrenheit (^{o}F) of packaged water can be determined using mercury-inglass thermometers. Values and standards have not been provided by WHO and GWCL for temperature of drinking water.

2.6 Chemical Parameters of Water

Generally, concentration of chemical components of drinking water has both direct and indirect impact on its bacteriological quality most especially when producers fail to adhere with values provided by (WHO, 1993).

2.6.1 pH pH is the measure of acidic nature of a solution, thus, the concentration of the hydrogen ions present in that solution. The hydrogen ion (H^+) activity in a solution determines the pH. The pH of drinking water is 7 (neutral), but the pH range recommended by WHO and GWCL is 6.5 to 8.5 (Table 14). Alkaline water can act as a weak buffer solution, depending on the concentration of carbonates and bicarbonates.

Therefore, an acidic pollutant may be present in such water, yet may not cause a change in pH of the water

(APHA, 1998). pH meter is the instrument used to measure pH in pH-units.

2.6.2 Total Alkalinity

Alkalinity is not a pollutant, it is a total measure of the substances in water which have acid-"neutralizing" ability and "buffer" its pH. Absolutely, pure water has a pH of exactly 7. Alkalinity is necessary for the survival of life because it buffers against pH changes and makes water less vulnerable to acid rain. The main sources of natural alkalinity are rocks, which contain carbonate, bicarbonate, hydroxide compounds, borates, silicates and phosphates. Limestone is rich in carbonates, so waters flowing through limestone regions generally are high in alkalinity- hence it"s good buffering capacity. On the other hand, granite does not have minerals that contribute to alkalinity (River Watch Network, 1992). High alkalinity in drinking waters may have an uncomfortable taste (Ramachandra & Solanki, 2006). Alkalinity is expressed in mg/l and there are no standards and guideline values proposed by the WHO and GWCL (GSA, 1998; WHO, 2007).

2.6.3 Total Hardness

Hardness of water is essential for strong teeth and bones, prevention of heart diseases, normal vascular activities and synthesis of protein (WHO, 2009).

On the other hand, industrial and domestic water users are concerned about the hardness of their water. Hard water requires more soap and synthetic detergents for home laundry and washing, and contributes to scaling in boilers and industrial equipment. Calcium and magnesium dissolved in water are the two most common minerals that make water "hard", and by a variety of other metals, water is an excellent solvent and readily dissolves minerals it comes in contact with. As water moves through soil and rock; it dissolves very small amounts of minerals and holds them in solution (WHO, 1993).

2.6.4 Total Magnesium and Calcium Hardness

Hard water is the type of water that has high mineral content formed when water percolates or washes through deposits of calcium and magnesium containing minerals such as limestone, chalk and dolomite. Hard water is generally not harmful to one‟s health WHO (2003), but can pose serious problems in industrial settings; hardness in water is often shown by a lack of suds formation when soap is agitated in water, and by the formation of lime scale in kettles and water heaters (*http://www.water-research.net*.). Test kits are used to test for water hardness in mg/l.

2.6.5 Nitrate

In 1974, the United States of American congress passed the safe drinking water act. This law requires EPA to determine the level of contaminants in drinking water at which packaged water will be wholesome for consumption in the country. To maintain potability of drinking water, the US federal states set standards called Maximum Contaminant Level Goals (MCLG) which refers to non-contaminant health risks contaminant level and exposure over a lifetime with an adequate margin of safety. Contaminants are any physical, chemical, biological or radiological substances or matter in water that make water unwholesome for drinking. The MCLG of nitrate (NO_3^-) is 10 mg/l while that of nitrite (NO_2^-) is 1 mg/l. US EPA (2006) has an enforceable regulation for nitrate, called a Maximum Contaminant Level (MCL) and ranged it at 0-10 mg/l. The same ranged is used for WHO and GWCL.

2.6.6 Sodium

It has also been suggested that for some microorganisms, sodium ions may limit oxygen solubility, interfere with cellular enzymes or force cells to expend energy to exclude sodium ions from the cell, all of which can reduce the rate of growth (Shelelf & Seiter, 2005). Sodium that exceeds the WHO guideline value of 200 mg/l can cause microbial cells such as amoeba and paramecium to undergo osmotic shock, causing loss of water from the cell and thereby resulting in cell death or retarded growth of children (Davidson, 2001). Sodium ion meter is used to measure sodium ion (Na^+) quantity in drinking water which is recommended to be below WHO guideline value of 200 mg/l.

2.6.7 Magnesium and Calcium

Water described as "hard" is high in dissolved minerals, specifically calcium and magnesium. Hard water is not a health risk, but a nuisance because of mineral build-up on fixtures and poor soap and/or detergent performance *(http://www research.net/hardn -ess.htm).* The WHO guideline values for calcium and magnesium for drinking water are (200 mg/l) and (150 mg/l) respectively.

2.6.8 Phosphorus and Phosphate

Phosphorus is in short supply in most fresh waters; hence, even a modest increase in phosphorus can cause excessive growth of plants and algae that deplete dissolved oxygen (DO) as they decompose. Phosphorus (P), like nitrogen (Nitrogen, found in ammonia, nitrite, nitrate), is an important nutrient for plants and algae. Excessive growth can also reduce the transparency of drinking water (RWN, 1991). Phosphate is an oxoanion salt of phosphorus which can be derived from iron/steel distribution pipes. However, distribution networks are very complex biochemical reactors that gather a large amount of phosphate with the tendency of exchanging them with the phosphate in drinking water (Comber, Cassé, Brown, Martin, Hillis & Gardner, 2011). WHO and GWCL have not provided any guideline value for phosphate. Spectrophotometer is used to measure nitrate in mg/l.

2.6.9 Fluoride

Fluoride occurs naturally at very low levels in drinking water. The amount depends on the type of rock in the area where your water supplies come from. Our tap water always contains less than 1.5 mg/l which is the level considered safe by the WHO. About ninety percent (90%) of the fluid added to public water supplies comes from silicofluorides, chemical produced mainly as by-products from the manufacture of phosphate fertilizers, according to the Community Water fluoridation (CDC). One study published in the fall of (2012) in the journal Environmental Health perspectives found a link between high fluoride levels found naturally in drinking water in China and elsewhere in the world, and lower IQs in children. The paper looked at the results 27 different studies 26 of which found a link between high fluoride in drinking water and IQ. The average IQ difference between high and lower fluoride areas was 7 points (APH, 1999).

2.6.10 Silica

Silica is found in the skeletal parts of various animals and plants. It is the most abundant element on earth after oxygen, and this is why most waters will contain some traces of dissolved silica *(http://www.freedrinkingwater.com/)*. Silica (silicon dioxide) is a compound of silicon and oxygen (SiO_2).It is a hard, glassy mineral substance which occurs in a variety of forms such as sand, quartz, sandstone, and granite. It can be measured by the use of silica portable photometer. In solution it can exist as silicic acid or silicate depending upon the pH. All natural water supplies contain suspended or colloidal silica. Silica is also found in certain foods including cucumbers, oats, brown rice, wheat, strawberries, avocados, onions, and root vegetables. It slightly dissolves in water hence sachet water dealers should always keep themselves clean to prevent contamination of drinking water. The WHO guideline value for silica in drinking water is (0 mg/l).

2.6.11 Sulphate

Sulphate mineral can result in scale built-up in water pipes similar to other minerals and may be linked with a bitter taste in water that can have a laxative effect on humans and young livestock. Sulphur-oxidizing bacteria reduce effects similar to those of iron bacteria (*http://www.water.research.net*). Elevated sulphate levels in combination with chlorine bleach can make cleaning clothes difficult. They convert sulphide into sulphate, producing a dark slime that can clog plumbing and/or stain clothing. Blacking of water or dark slime coating the inside of toilet tanks may indicate a sulphur-oxidizing bacteria problem. Sulphur-oxidizing bacteria are less common than sulphur-reducing bacteria. WHO guideline value for sulphate is 400 mg/l; it can be measured by the use of turbid meter (UNICEF, 2003).

2.6.12 Chloride

Research has indicated that daily water consumption is 1.5 litres and that the average concentration of chloride in drinking water is 10 mg/l, the average daily intake of chloride from drinking water can be estimated to be approximately 15 mg per person (NRCC, 1977). Chloride is a greenish-yellow gas that dissolves easily in water. It has a pungent, noxious odour that some people can smell at concentrations above 0.3 parts per million. Because chloride is an excellent disinfectant, it is commonly added to most drinking water supplies. The intake of water therefore constitutes only about 0.25% of average intake from food (NRCC, 1977). In parts of the world where chlorine is not added to drinking water, thousands of people die each day from waterborne diseases like typhoid and cholera (Weinberg, 1986). It is widely used as a bleaching agent in textile factories and paper mills, and it is an important ingredient in many laundry bleaches. Free chlorine (chlorine gas dissolved in water) is toxic to fish and aquatic organisms, even in very small amounts. The WHO value for chloride is (250 mg/l).

2.6.13 Bicarbonate

In almost all water supplies bicarbonate (HCO_3^-) ion is the principal alkaline constituent. Alkalinity in drinking water supplies is often controlled and in most occasions does not exceed 300 mg/l. Bicarbonate alkalinity is introduced into the water by CO_2 dissolving carbonate–containing minerals. Alkalinity control is important in boiler feed water, cooling tower water, and in the beverage industry. Alkalinity neutralizes the acidity in fruit flavours; and in the textile industry. Alkalinity is known as a „‟buffer‟‟‟ *(http://www.aquapurefilters.com/.../bicarbonate).* pH range of 5.0 to 8.0 always form a balance between excess CO_2 and bicarbonate ions in most cases. Removing the free CO_2 through aeration can reduce the bicarbonate alkalinity. Feeding acid to lower the pH can also reduce the alkalinity. At pH 5.0 there is only CO_2 and 0 Alkalinity. A strong base anion exchanger will also remove alkalinity *(http://www.aqua purefilters.com/.../bicarbonate).*

2.7 Bacteriological Parameters of Water

Coliform organisms are suitably used as microbial indicators of drinking water quality largely because they are easy to detect and enumerate in water (WHO, 1993). Coliform bacteria have classically been translated into specific chemical reactions or the appearance of characteristic colonies on commonly used media (US EPA, 2013). For the purpose of this study, total and faecal coliform qualities of sachet water were determined.

2.7.1 Total Coliform

The total coliform rule (TCR), the National Primary Drinking Water Regulation (NPDWR), was published in 1989 and became effective in 1990, in the rule, health goal (MCLG) and legal limits (MCLs) set by EPA for the presence of total coliform in water is zero. Also, the WHO Guideline and GWCL Standard values set for total coliform is zero. This is because there have been water borne disease out breaks in which researchers have found very low levels of coliform, an indication that any levels of indicator organisms have health risk (US EPA, 2013). The purpose of the 1989 TCR is to protect public health by ensuring the integrity of the drinking water distribution system. The rule requires all public water systems (PWSs) to monitor for the presence of total coliform in the distribution system at a frequency proportional to the number of people served. Systems which serve fewer than 1,000 people may test once a month or less frequently, while systems with 50,000 customers are to test at least 60 times per month and those with 2.5 million customers test at least 420 times per month. Membrane Filter method was used for testing the sachet water samples with membrane pore sizes of 0.45 micron, it is widely used in testing for indicator organisms at the Water Quality Laboratory in Tamale. Description of the method is also contained in a book written by (Obiri-Danso & Abaidoo, 2008).

2.7.2 Faecal Coliform

Large quantities of faecal coliform bacteria water are not harmful according to ObiriDanso and Abaidoo (2008) but may indicate a higher risk of pathogen being present in the water. WHO and U.S. EPA and GWCL have also established an MCLG and MCL of zero for faecal coliform based on the monitoring results for total coliform (US EPA,
2006). Membrane Filtration method was used for testing the sachet water samples with membrane pore sizes of 0.45 micron. For treated drinking water, Colorado Department of Public Health and Environment Water Quality Control Division (CDPHE-WQCD) regulations are similar to those of US EPA; there cannot be any faecal coliform in treated drinking water (CDPHE-WQCD Primary Drinking Water Regulations). In the case of domestic water supply, a CDPHE-WQCD regulation states that faecal coliform count shall not be detectable in any 100ml sample. Membrane Filter Method is used to test for faecal coliform in water samples (US EPA, 2006).

2.8 Requirement for Sachet Water Production

The FDA requires documented information on the premises (nature of building) and equipment of sachet-water factories. This includes general information on interior surfaces, drainage system, ventilation, water and electrical systems. The type and make up of equipment used and the maintenance and standard operating procedures, quality control as well as the equipment validation and calibration information are also required (FDA, 2005). The design and placement of equipment used is checked to ensure that it can be easily cleaned and disinfected and properly maintained and used. Floor plans that show the positions of equipment and facilities are required. As described by the FDA, other guidelines that relate to the premises include: Smooth flooring with no cracks that can possibly harbour vectors; Fluorescent lights with shatter proof bulbs to contain the glass particles if the bulbs should break; Walls coated or clad with washable material such as tiles or oil-based paints; Wiring and electrical connections and devices covered by electrical cover plate (FDA, 2005).

The staffs working with sachet-water production (or other food and drug products) are required to undergo periodic health checks to ensure they are free of any communicable diseases. They are also required to have protective clothing, such as disposable gloves. Other documented information required by the FDA , as related to hygiene, includes the cleaning and disinfecting agents used, the pest management strategies, the disinfection standard operating procedure and, where applicable, the effluent discharge and treatment (FDA, 2005).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study area is the Tumu Township where most of the sachet water in the Sissala East District is produced and distributed to other villages under the District. Tumu is the capital town of the Sissala East District of the Upper West Region and has a population of about five thousand five hundred (5,500) as at 2006 according to Ministry of Health/Ghana Health Service (MOH & GHS, 2006). Sissala East has a total land area of

7,115 km^2, about forty percent (40%) of the total land area of the Upper West Region. About eighty-eight percent (88%) of the population is Sissala and the rest comprises Dagaati, Waala, Mossi and other minority tribes. Tumu shares boundaries with Navrongo to the east, Wa in the south, Leo (Burkina Faso) in the north and Hamele to the west. The immediate villages surrounding Tumu in the Sissala East District are Pieng in the South, Kupulma at the North, Dimanjan in the East and Nahadakui in the West (Figure 1).

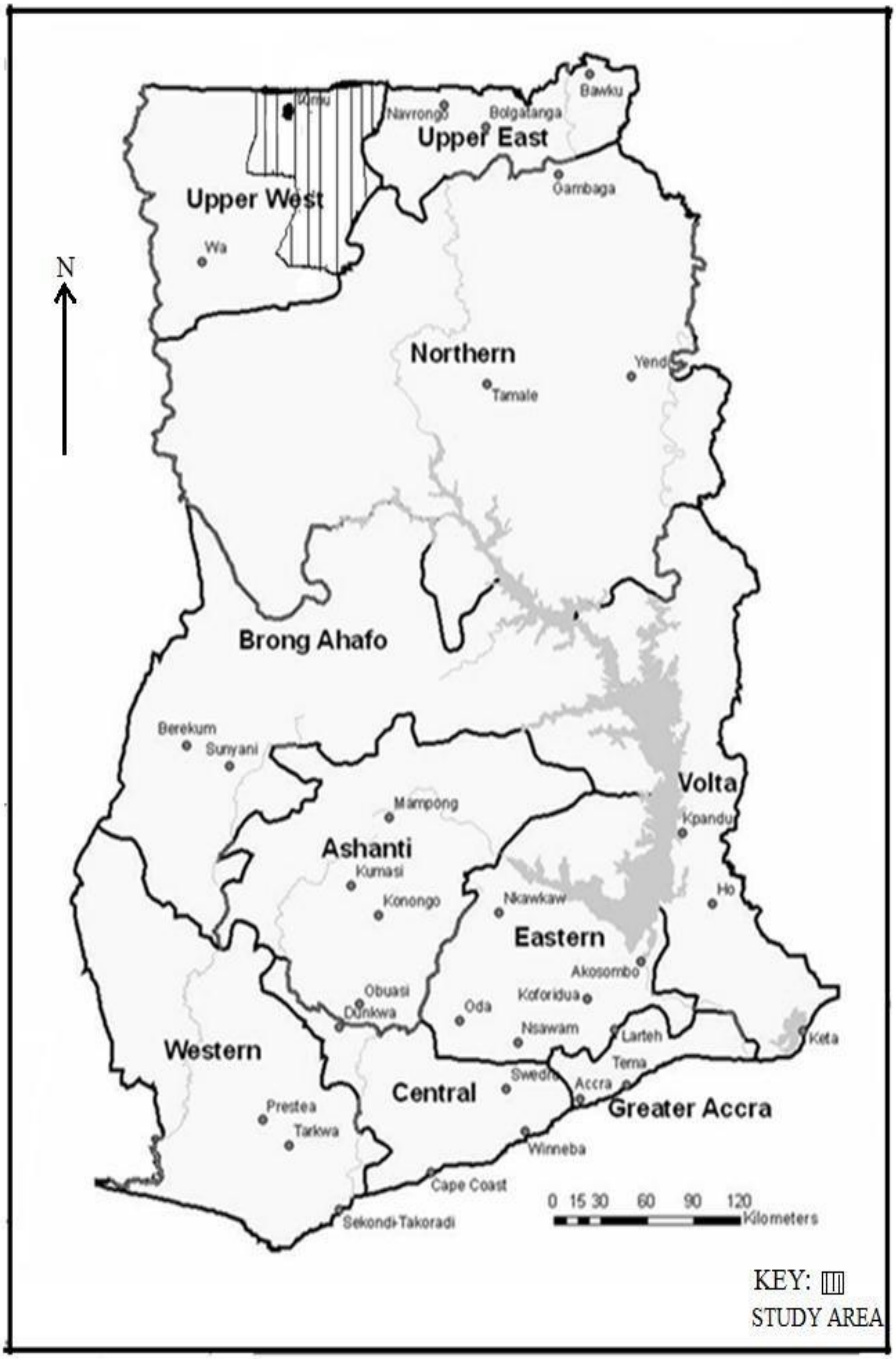

Figure1: Map of Ghana showing the location of Tumu in the Upper West Region.

Adapted from Van Calcar (2006).

3.2 Study Setting and Design

Three different brands of bagged sachet water manufactured and sold in Tumu were chosen for the study. Batch numbers of each brand was identified and the chain traced for samples from all the three points by random sampling technique, Kumekpor (2002) defined random sampling technique as the type of sampling where there is an equal chance of selecting each unit of the population being studied when creating samples. Codes were used to indicate points of sample collection for all three companies, for company TWP-A, FA, WA and VA codes were used. FB, WB and VB were used for company TWP-B and FC, WC and VC represented samples from three points of company TWP-C.

For the first sampling, FA_1, $WA_1$and VA_1(FA_1 stands for sachet water samples collected from factory point, WA_1means sachet water samples collected from wholesale point and VA_1 refers to sachet water samples collected from vendor point)were used for company TWP-A.FB_1, WB_1 andVB_1 were used for company TWP-B and FC_1, WC_1 and $VC_1$for company TWP-C. This process was done in triplicate for all three companies with subscripts two (2) and three (3) used for the second and third sampling.
On each occasion samples were sent for testing to confirm or reject the null Hypothesis.
Definition of some terms;

- ✓ Producers-those who produce and sell sachet water
- ✓ Wholesalers-dealers who buy sachet water from producers and sell to vendors
- ✓ Vendors-street sellers of sachet waters, usually carried in small pans

3.3 Sampling Technique

To determine the bacteriological quality of sachet water produced in Tumu in the Sissala East District of Upper West Region, nine (9) plastic bagged sachet water samples were taken from each of the three different companies coded as TWP-A, TWPB and TWP-

C in Tumu, Ghana. The standard for sampling was based on the Ghana Standards Authority list of accredited sachet water producers in the region. Water samples of the three brands from different manufacturers were bought within the Tumu Township. In all, three samples were obtained from each point (that is, from source, wholesale and vendor), making nine samples for each brand. Collected samples were transported to the water quality laboratory at Tamale in cold box lined with ice block chips (with temperature less than 4^{o}C) for each trip. All tests were done in triplicate. When testing was not possible in four to six hours the samples were transferred to a refrigerator to be tested within 24 hours. In all, eighty one (81) sachets of were tested; twenty seven (27) from each company.

3.4 Laboratory Analysis of Physical Parameters

Samples were analysed for colour, TDS, conductivity, turbidity, and temperature using appropriate measuring instruments, methods and techniques used in most water testing laboratories (AWWA & APHA, 1998) and (UNICEF, 2003).

3.4.1 Colour (Test Strip Method)

To 10 ml sample of water in a test tube, reagent area of the test strip was dipped into the sample, after two minutes it was removed and the colour compared with that of the colour chart. Reading was taken directly from colour chart in TCU (AWWA & APHA, 1998).

3.4.2 Conductivity and TDS (Digital Meter Method)

To 10 ml of water sample in a test tube digital meter was dipped and reading taken directly from meter after two minutes in µs/cm. Digital meter can also be read in mg/l for TDS.

3.4.3 Turbidity

10 ml of water sample was pipetted into a test tube, agitated and kept until air bubbles disappeared before sample was poured into a cell. Well mixed sample was poured into cell and immersed in an ultrasonic bath for 1 to 2 minutes causing complete bubble released. Turbidity was then read in NTU from instrument display.

3.4.4 Temperature

To a sizable amount of water sample in a container, the thermometer was placed at least 4 inches below the surface to the bottom of container. The set up was allowed to stay for at least one minute to allow the temperature reading to stabilise at a constant temperature reading, before thermometer reading was taken directly from meter in ^{o}C (UNICEF, 2008).

3.4.5 Water Hardness (Ethylenediamintetra acetic acid-EDTA)

To determine hardness of water, 100 ml aliquots of the water samples were measured into three (3) 250-ml Erlenmeyer flasks. To each sample, magnesium solution and Eriochrome Black T indicator was added. The resulting solution was then titrated with standardised EDTA solution. After correcting for the volume of titrates by subtracting the indicator blank, the molar concentration of calcium in the hard water sample was determined and recorded as number of milligrams of $CaCO_3$ per litre.

3.5 Laboratory Analysis of Chemical Parameters

Samples of chemical parameters were analysed using appropriate measuring instrument, methods and techniques used in most water testing laboratories (AWWA & APHA,

1998) and (UNICEF,2003).

3.5.1 Fluoride (Spadns Method)

To determine fluoride content, 5 ml distilled water was measured into two test tubes. One of the tubes was used as the non-fluoride sample (blank). A control standard of 1 ml/l was prepared and measure 5 ml. 0.5 ml Spadns reagent was added to each sample /tube and the absorbencies were read at 570 nm using raw distilled water to zero the machine (distilled water without reagent).

3.5.2 Nitrate-Nitrogen (Hydrazine Reduction Method)

To determine nitrogen content, 10 ml of the sample was pipetted into a test tube. Afterwards, 1ml of 0.3 NaOH was added and mixed thoroughly. 1ml of reducing mixture was added while shaking gently to mix. The test sample was then heated at 60 ^{o}C for 10 mins in a water bath and cooled to room temperature before adding 1ml colour developing reagent. After mixing thoroughly the absorbance was read at 520 nm on a spectrophotometer.

3.5.3 Phosphate (PO_4^{3-}–P)-(Stannous Chloride Method)

To determine phosphate content, 0.4 ml molybdate reagent and 0.05 ml (1 drop) stannous chloride reagent were added to 10 ml water sample. After 10 mins, but before 12 mins, the absorbance was measured at 690 nm on a spectrophotometer.

3.5.4 Silica (Molybdosilicate Method)

To determine the concentration of silica 10 ml sample was measured and 0.2 ml, 1 ml HCl and 0.4 ml ammonium molybdate reagent were added in rapid succession. After mixing, the solution was allowed to stand for 10 mins before adding 0.4 ml oxalic acid solution. The absorbance was determined after 2 mins at 410 nm.

3.5.5 Sulphate (Turbidimetric Method)

To determine concentration of Sulphate, 10 ml sample was measured into a test tube and 0.5 ml conditioning reagent added. The solution was mixed by stirring. A spoonful of barium chloride crystals was added while still stirring. Finally, the absorbance was measured at 420 nm on the spectrophotometer.

3.6 Laboratory Analysis of Microbial Parameters

Samples were analysed for faecal coliforms, *E. coli*, and total coliform bacteria by the membrane filtration technique AWWA and APHA (1998) using Millipore HA, 0.45 mm pore-size membrane filters (Millipore Corp., Bedford, MA).This technique is used in most water testing laboratories. A series of tests were conducted on the pure isolates of the Gram positive and Gram negative isolates, in order to identify the exact species of organisms (Gram negative isolates total and faecal coliforms).

3.6.1 Isolation and Enumeration of Faecal Coliforms

Faecal coliforms were estimated following the procedure previously described for total coliforms. However it was incubated at 44 ^{o}C for 24 hrs. Tubes showing acid and gas productions after incubation were confirmed by plating on MacConkey agar in a dilution of 10^{-1} to 10^{-6} and examined for typical colonies. Counts per 100 ml were calculated from MPN tables (Obiri-Danso & Abaidoo, 2008).

3.6.2 Isolation and Enumeration of Escherichia Coli

Escherichia coli was determined by passing water sample through a membrane (e.g. 0.45 µm) with pore sizes small enough to physically retain the bacterium on the filter surface while allowing the water to filter through the membrane (using a vacuum pump system). The filter was then placed onto a solid growth medium (agar) which is selective or differential for growth of the target bacteria and incubated for 24 hrs at 44.51 ^{o}C in a dilution of 10^{-1} to 10^{-6}.

3.6.3 Enumeration of Total Heterotrophic Bacteria or Total Viable Count (TVC)

Estimations of the total population of heterotrophic bacteria in the water samples were obtained using the pour plate technique. Dilutions of 10^{-1} to 10^{-6} of water samples were prepared in 0.1% buffered peptone water in triplicate. 1 ml aliquot of each dilution was inoculated into10 ml of molten plate count agar (Lab M, Bury, UK) in universal bottles. These were then thoroughly mixed, poured into sterile Petri dishes and incubated for 48hrs at 25 ^{o}C. Petri dishes from dilutions containing between 20 and 50 discrete colonies were counted and the results expressed as the number of bacteria per millilitre (AWWA & APHA, 1998).

3.6.4 Enumeration of Total Microbial population

Total microbial populations were estimated using the pour plate technique. Sample dilutions of 10^{-6} to 10^{-10} were prepared in 0.1% buffered peptone water (BPW) (oxoid) and 1 ml aliquots of each dilution inoculated in triplicate into 20 ml each of total plate count agar (lab M) in universal bottles. These were then thoroughly mixed and poured into sterile petri dishes and incubated for 48 hrs at 37 ^{o}C. Plates of dilutions showing discrete colonies were counted and expressed as cfu ml^{-1}. Isolates were purified by continuous subculture on nutrient broth. All isolates were stored on nutrient agar slants in bijoux bottles and kept at -4 ^{o}C.

3.6.5 Presumptive Identification of Microbial Isolates

To confirm the isolates, Gram stain was carried out on a smear of the colony and examined under oil immersion at x 100 magnification. Aseptically, one drop of sterile distilled water was placed on a clear microscopic slide. A colony was picked up with a sterile loop to make a thin smear of cells in the distilled water. The smear was allowed to dry and fixed by removing the slide in and out of a Bunsen flame three or four times. The slide was placed on a starting rack and the surface over laid with crystal violent solution for one minute. The slide was then thoroughly washed with alcohol as a decolouriser until no more violet washed off. The slide was washed with distilled water and counterstained with safran in water and blot dried with filter paper. It was then examined under x100 oil immersion.

3.7 Data Management and Analysis

Data collated from the field were cleaned and appropriately arranged for analysis based on the stated objectives of the study. Raw data were processed into means and trend and/or variations presented in tables and bar graphs with their degrees of dispersions about the mean value (standard deviation). With the help of IBM® SPSS® Statistics, Version 20.0 (IBM Corporation), and Microsoft Office Excel/Spread sheet (2010), a statistical analysis for hypothesis testing via Analysis of Variance (ANOVA) was conducted to determine statistical significance($p<0.05$) of the variations among the mean values tabulated for the various parameters and treatments under investigation. Where the ANOVA identified significant differences to exist at $p<0.05$, Least Squared

Difference (LSD), also constructed at $p < 0.05$ was used to locate the pair of treatment means that were significantly different. In all statistical analysis for significant differences, ninety-five percent (95%) confidence interval was assumed.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

Physico-chemical and bacteriological quality parameters measured are presented in this section for each of the three companies respectively. Comparison between the parameters measured for the various manufacturers are also made.

4.2 Physical Properties of the Water Samples

4.2.1 Physical Properties of the Water Samples from TWP-A

Among the physical properties of the water samples from TWP-A, variations existed in all the parameters except colour. However, these differences were not significant at 5%

significance level (ANOVA Table, Appendix 1.1). Data from the study (Table 2) shows that the highest mean TDS value (100.53 mg/l) and conductivity (167.87 µs/cm) for TWP-A water samples were recorded for the vendor water samples, whiles their respective values in the manufacturer samples were lowest (97.00 mg/l) and (161.86 mg/l). The standard deviations for the TDS indicate that TDS values of vendor water samples were widely distributed (8.72) about the mean, an indication of imprecision of TDS of the water samples. However, statistical analysis for the differences among the TDS and conductivity values revealed that at $p < 0.05$, the differences between the means were not significant (0.72 & 0.74 respectively). The vendor water samples again recorded higher fluctuations in the water conductivity values such that the standard deviation was discovered to be 15.36. Table 2 further shows that the values for colour, for all the sample points of TWP-A were the same and stood at 2.5 Hz, even for replicate values, such that standard deviation was 0.00 for all. Turbidity values were generally precise such that 1.33 NTU value was recorded for wholesale samples, followed by 1.67 NTU recorded for both producer and vendor samples. The temperature of all the samples stood at 27.17 ^{o}C. Differences between the means of all the physical parameters were not significant ($p < 0.05$).

Table 2: Physical Parameters for TWP-A Samples

PARAMETER	UNIT	MEANS FOR TWP-A SAMPLE POINTS			p-Value (α = 0.05) 95% Confidence Interval	LSD
		Factory	Wholesale	Vendor		
TDS	mg/l	97±2.57	97.93±2.00	100.53±8.72	0.72	13.03
Conductivity	µs/cm	161.87±4.59	163.6±2.96	167.87±15.36	0.74	22.81
Colour	Hz	2.5±0.00	2.5±0.00	2.5±0.00	N/A	0
Turbidity	NTU	1.67±0.58	1.33±0.58	1.67±0.58	0.73	1.4
Temperature	^{O}C	27.17±1.69	27.17±1.86	27.17±1.96	1	4.45

4.2.2 Physical Properties of the Water Samples from TWP-B

Contrary to the results of the physical parameters of sachets water for TWP-A, a higher mean value of 109.20 mg/l was recorded for TDS and 182.30 µs/cm mean value for conductivity in the wholesale water samples (Table 3) for company TWP-B. Although TDS for the samples from the producer was the lowest (74.9 mg/l), the standard deviation was significantly the highest (53.87), an indication of wide inconsistencies within the replicate samples. Test of significance proved that there was no difference between the mean values of TDS ($p=0.36$) and conductivity ($p=0.9$). Turbidity increased gradually from the producer (1.33 NTU), through the wholesaler (1.67 NTU) to the vendor (2.00 NTU). Differences at $p < 0.05$ were not significant ($p = 0.3$). Whiles the samples from both the producer and the wholesaler achieved equal standard deviation (0.58), values for the vendor samples were more coherent (standard deviation of 0.00). It follows that, the mean values for all the parameters from the sample points of TWP-B were not significantly different (Table 3). ANOVA tables for the physical parameters of water samples from TWP-B are presented in Appendix 1.2.

Table 3: Physical Parameters for TWP-B Samples

PARAMETER	UNIT	MEANS FOR TWP-B SAMPLE POINTS			P-VALUE ($\alpha = 0.05$) 95% confidence interval	LSD
		Factory	Wholesale	Vendor		
TDS	mg/l	74.9±53.87	109.2±3.91	109.03±3.36	0.36	75.7
Conductivity	µs/cm	180±5.80	182.3±6.15	181.1±6.18	0.9	14.65
Colour	Hz	2.5±0.00	2.5±0.00	2.5±0.00	N/A	0
Turbidity	NTU	1.33±0.58	1.67±0.58	2±0.00	0.3	1.14
Temperature	^{O}C	27.3±2.04	27.37±1.83	28.23±0.68	0.75	3.96

4.2.3 Physical Properties of the Water Samples from TWP-C

Data recorded for the TWP-C sachets water samples shows that, the highest mean values for TDS (129.8 mg/l), conductivity (211.33 µs/cm) and temperature (27.53 ^{o}C) were recorded for producer samples, whiles the wholesale water samples were the lowest for TDS and conductivity (128.2 mg/l and 212.67 µs/cm respectively). Standard deviations in the replicate values of the TDS show that it ranged from 7.11 in the wholesale to 7.99 in the vendor samples. Again, standard deviations for the conductivity were in ascendency from the producer (9.29), through the wholesale (10.12) to the vendor (12.49). These imply that the conductivity values for all the TWP-C sample points are imprecise and widely distributed about the means. As in the other water samples, colour was same for all the sample points (2.5 Hz) with no replicate deviations, an indication of highest precision. Statistical analysis proved that the means of all the physical parameters of the TWP-C water samples were not significantly different at $p < 0.05$ (Table 4).

Table 4: Physical Parameters for TWP-C Samples

PARAMETER	UNIT	MEANS FOR TWP-C SAMPLE POINTS			P-VALUE (α = 0.05) 95% confidence interval	LSD
		Factory	Wholesale	Vendor		
TDS	mg/l	129.8±7.95	128.2±7.11	129.2±7.99	0.97	18.64
Conductivity	µs/cm	211.33±9.29	212.67±10.12	216±12.49	0.86	25.97
Colour	Hz	2.5±0.00	2.5±0.00	2.5±0.00	N/A	0
Turbidity	NTU	1.67±0.58	2±0.00	2±1.00	0.79	1.62
Temperature	^{O}C	27.53±1.99	27.47±2.1	27.33±2.49	0.99	5.34

4.2.4 Comparison between Physical Parameters of TWP-A, TWP B and TWP-C

Comparison of the physical parameters made among the three different sachets water used for the study indicated that TDS was highest for TWP-C (129.07 mg/l) and lowest for TWP-B (97.71 mg/l) (Table 5), although standard deviation was highest for TWP-B (32.01) and lowest for TWP-A (4.92). It follows that significant differences ($p<0.05$) existed between the TDS of the sachets water for the three companies under study ($p = 0.002$) (Appendices 1.4.1). Therefore, it was identified that TDS for TWP-C was significantly different from all the rest. Again, highest conductivity was recorded in TWP-C (213.33 μs/cm) with a deviation of 9.51 distributions about the mean value, whiles TWP-A had the lowest conductivity value (164.44 μs/cm) with a deviation of 8.58 from the mean. It was revealed from the ANOVA (Appendix 1.4.2) that differences were significant at $p < 0.05$ ($p = 1.06 \times 10^{-11}$), such that each mean conductivity value for the various categories of the sachets water under study was different ($p < 0.05$) from the others. The rest of the physical parameters were identified by the ANOVA Table not to be significantly different at $p < 0.05$ (Appendices 1.4.3, 1.4.4 & 1.4.5), though variations existed, except for colour.

Table 5: Mean Physical Parameters for TWP-A, TWP-B and TWP-C Compared

PARAMETER	UNIT	MANUFACTURERS			P-VALUE (α = 0.05) 95% confidence interval	LSD
		TWP-A	TWP-B	TWP-C		
TDS	mg/l	98.49±4.92^{a}	97.71±32.01^{a}	129.07±6.7^{b}	0.002	30.6
Conductivity	μs/cm	164.44±8.58^{a}	181.13±5.33^{b}	213.33±9.51^{c}	1.06×10^{-11}	12.84
Colour	Hz	2.5±0.00	2.5±0.00	2.5±0.00	N/A	0
Turbidity	NTU	1.56±0.53	1.67±0.5	1.89±0.6	0.43	0.87
Temperature	^{o}C	27.17±1.59	27.63±1.48	27.44±1.91	0.83	2.68

Means with the same letters are not different

4.3 Chemical Properties of Water Samples

4.3.1 Chemical Properties of Water Samples from TWP-A

The chemical parameters that were assessed and their respective values for the various sample points of TWP-A are presented in Table 6. Statistical analysis for all the parameters proved to be insignificant at $p < 0.05$ (ANOVA Tables, Appendix 2.1), although higher imprecision existed among replicate values of total alkalinity, bicarbonate, silica, total hardness, calcium hardness and magnesium hardness. Total alkalinity decreased from the producer samples (57.33 mg/l) through the wholesalers (54.67 mg/l) to the vendor samples (48.67 mg/l). Highest imprecision standard deviation value of (14.05) was found in the wholesaler samples, whiles in the vendor samples a standard deviation value of 9.87 was recorded. Bicarbonate was also highest in the producer samples (69.97 mg/l) and lowest in the vendor samples (59.37 mg/l). It follows that, whiles the wholesale samples recorded the highest silica value (47.17 mg/l), it also recorded the highest distribution of the replicate values, such that standard deviation was significantly highest (7.81) compared to 2.16 for wholesale and 4.78 for vendor samples. The study further revealed that vendor water samples had highest total hardness (59.33 mg/l), with the wholesale having the lowest (52.67 mg/l). Fluctuations in the replicate values of the total hardness of the water samples from TWP-A were wide and randomly distributed about the means. pH values ranged from 6.90 to 6.93 in the producer samples to the vendor samples, indicating slight acidity. Standard deviations for the pH values were ascertained to be insignificant, ranging from 0.28 to 0.33, an indication of high precision of the replicate values. Of particular interest was the imprecision standard deviation of (15.28) identified in the magnesium hardness values for the producer sample (24.61 mg/l), and 12.2 deviations in the wholesale samples (19.24 mg/l).

Table 6: Chemical Parameters for TWP-A Samples

PARAMETER	UNIT	MEANS FOR TWP-A SAMPLE POINTS			P-VALUE (α = 0.05) 95% confidence interval	LSD
		Factory	**Wholesale**	**Vendor**		
pH	pH-unit	**6.9±0.33**	6.92±0.3	6.93±0.28	0.99	0.74
Total Alkalinity	mg/l	57.33±12.22	54.67±14.05	48.67±9.87	0.69	29.48
Bicarbonate	mg/l	69.97±14.92	66.7±17.16	59.37±12.05	0.69	35.99
Sulphate	mg/l	3.32±1.31	3.85±1.55	4.31±1.62	0.73	3.63
Chloride	mg/l	6.65±0.56	7±1.00	7.32±0.59	0.58	1.81

Nitrate	mg/l	7.73±3.31	8.42±2.83	8.24±3.01	0.96	7.4
Phosphate	mg/l	0.09±0.05	0.39±0.33	0.2±0.16	0.29	0.52
Fluoride	mg/l	0.64±0.09	0.57±0.02	0.59±0.02	0.27	0.13
Calcium	mg/l	12.27±3.6	13.33±0.92	10.94±3.22	0.61	6.88
Magnesium	mg/l	5.97±3.71	4.67±2.97	7.75±0.83	0.45	6.74
Sodium	mg/l	11.27±1.36	11.27±1.27	11.1±1.22	0.98	3.11
Potassium	mg/l	3.3±0.26	13.2±17.15	3.27±0.40	0.42	24
Silica	mg/l	47.17±7.81	44.03±2.16	46±4.78	0.78	13.16
Total Hardness	mg/l	55.33±11.02	52.67±10.07	59.33±11.02	0.76	25.95
Cal. Hardness	mg/l	30.73±9.07	33.43±2.31	27.4±8.13	0.61	17.34
Mag. Hardness	mg/l	24.61±15.28	19.24±12.2	31.93±3.41	0.45	27.76

4.3.2 Chemical Properties of Water Samples from TWP-B

Results for the TWP-B sachets water samples under study revealed that all the mean values for the various parameters across the sample points were not statistically significant at $p < 0.05$ (Appendix 2.2) with the exception of silica (Table 7), which recorded p –value of 0.02 in the ANOVA Table (Appendix 2.2.13). The results further indicated that, with the exception of total alkalinity, bicarbonate and magnesium hardness, the replicate values for most of the parameters across the three sample points were very precise and clustered about the mean values. It follows that mean silica levels was significantly higher at $p < 0.05$ ($p = 0.02$), with a recorded higher mean value of (49.26 mg/l) in producer samples and a lower mean value of (6.61 mg/l) in wholesale samples (Table 3); silica in the vendor samples were not significant from the rest, whiles the factory water silica levels were significant from those of the wholesale water silica levels. The study revealed that total alkaline was highest for the producer samples (61.33 mg/l) and lowest for the vendor samples (53.33 mg/l). The replicate values for the total alkalinity were widely dispersed such that the highest standard deviation (16.04) was found in the producer samples, 15.04 for the wholesale samples and 8.33 for the vendor samples. Again, magnesium hardness values decreased from the point of manufacturer (31.93 mg/l) to the consumer point (26.33 mg/l). The highest dispersion about the mean (15.15) for the magnesium hardness was recorded in the producer samples. Likewise, a higher mean values for bicarbonate (74.83 mg/l), sulphate (4.08 mg/l), chloride (6.97 mg/l), phosphate (0.27 mg/l), magnesium (7.78 mg/l), and potassium (4.76 mg/l), were recorded in producer samples. Similarly, a lower mean value for sulphate (2.73 mg/l), magnesium (6.61 mg/l), chloride (6.64 mg/l) and potassium (4.66 mg/l) were recorded in wholesale samples. Whilst pH (7.13 pH-units) was recorded as the higher mean value in wholesale samples and 7.07 pH-units as its lower mean value in producer samples, higher mean values for nitrate (3.13 mg/l) and calcium (12.96 mg/l) were recorded in vendor samples. pH values were within the neutral range. Also, (3.05 mg/l) was recorded for nitrate as its lower mean value in wholesale samples, whilst a lower mean value of (11.20 mg/l) was recorded for calcium in producer samples. For fluoride the higher recorded mean value of (0.62 mg/l) was observed in Wholesale samples whilst (0.55 mg/l) was recorded as its lower mean value in vendor samples (Table 7).

Table 7: Chemical Parameters for TWP-B Samples

PARAMETER	UNIT	MEANS FOR TWP-B SAMPLE POINTS			p-Value (α = 0.05) 95% Confidence Interval	LSD
		Factory	Wholesale	Vendor		
pH	pH-unit	7.08±0.22	7.13±0.16	7.08±0.23	0.93	0.5
Total Alkalinity	mg/l	61.33±16.04	59.67±15.04	53.33±8.33	0.76	32.9
Bicarbonate	mg/l	74.83±19.6	71.47±18.32	64.63±9.64	0.75	39.88
Sulphate	mg/l	4.09±0.92	2.73±0.75	3.2±0.18	0.13	1.68
Chloride	mg/l	6.98±2.61	6.64±2.85	6.71±2.79	0.99	6.66
Nitrate	mg/l	3.65±3.27	3.05±3.19	3.13±3.2	0.97	7.8
Phosphate	mg/l	0.27±0.27	0.17±0.14	0.16±0.14	0.75	0.46
Fluoride	mg/l	0.62±0.03	0.62±0.09	0.56±0.03	0.35	0.14
Calcium	mg/l	11.2±2.88	13.33±2.57	12.97±1.94	0.57	6.05
Magnesium	mg/l	7.78±3.7	6.61±1.55	6.73±2.62	0.85	6.7
Sodium	mg/l	11.37±1.1	11.33±1.16	11.33±1.15	1	2.76
Potassium	mg/l	4.77±0.47	4.67±0.57	4.7±0.56	0.97	1.29

Silica	mg/l	49.27±2.76[a]	41.67±2.21[b]	44.9±1.67[ab]	0.02*	5.47
Total Hardness	mg/l	60±8.00	57.33±1.15	57.97±3.44	0.8	12.29
Cal. Hardness	mg/l	28.07±7.27	33.5±6.47	34.1±4.00	0.46	14.72
Mag. Hardness	mg/l	31.93±15.15	27±6.18	26.33±9.09	0.79	26.19

***Means with the same letters are not significant ($p < 0.05$)**

4.3.3 Chemical Properties of Water Samples from TWP-C

Data recorded for the chemical parameters of TWP-C sachets water samples proved that pH mean value of 7.15 pH-units was recorded as the highest in vendor samples and (7.07 pH-units) recorded as the lowest mean value in producer samples (Table 8).Higher mean values of bicarbonate (98.30 mg/l), chloride (8.64 mg/l), calcium (15.30 mg/l) and potassium (4.40 mg/l) were recorded in producer samples. On the other hand, lower mean values of bicarbonate (90.30 mg/l), potassium (4.33 mg/l) and chloride (7.98 mg/l) were recorded in vendor samples, whiles for calcium; a lower mean value of (10.50 mg/l) was recorded in wholesale samples. Likewise, nitrate (2.33 mg/l), phosphate (0.36 mg/l), fluoride (0.79 mg/l) and sodium (12.06 mg/l) recorded higher mean values in wholesale samples. Also, the lower mean values for nitrate (2.10 mg/l), phosphate (0.11 mg/l), fluoride (0.54 mg/l) and sodium (12.03 mg/l) were all recorded in producer samples (Table 8). Sulphate levels in the vendor samples were significantly higher than the producer samples at $p < 0.05$ ($p = 0.03$); other mean differences did not exist ($p < 0.05$). However, the differences in means of the entire sample points for all the other parameters under study were not significantly different at $p < 0.05$ [Table 8; ANOVA Tables (Appendix 2.3)]. It follows from the data that, standard deviations are highest in total alkalinity, bicarbonate, silica and total hardness for producer water samples (25.01, 30.36, 6.95 and 15.1 respectively), calcium hardness and magnesium hardness for vendor sample water (24.76 and 29.23 respectively). Thus, producer samples were widely distributed about the means. The rest of the parameters for all the sample points were significantly low, an indication of high precision.

Table 8: Chemical Parameters for TWP-C Samples

PARAMETER	UNIT	MEANS FOR TWP-C SAMPLE POINTS			p-Value (α = 0.05) 95% Confidence Interval	LSD
		Factory	Wholesale	Vendor		
pH	pH-unit	7.08±0.27	7.09±0.26	7.15±0.2	0.93	0.59
Total Alkalinity	mg/l	80.67±25.01	75.33±20.43	74±18.33	0.92	51.94
Bicarbonate	mg/l	98.3±30.36	92.07±25.06	90.3±22.36	0.93	63.33
Sulphate	mg/l	2.17±0.88[a]	2.78±0.96[ac]	4.31±0.21[c]	0.03	1.85
Chloride	mg/l	8.64±0.56	8.31±0.6	7.98±0.03	0.3	1.14
Nitrate	mg/l	2.11±1.42	2.33±1.16	2.33±1.28	0.97	3.13
Phosphate	mg/l	0.11±0.09	0.36±0.35	0.31±0.3	0.53	0.66
Fluoride	mg/l	0.54±0.39	0.79±0.17	0.56±0.41	0.63	0.83
Calcium	mg/l	15.3±1.48	10.5±8.14	12.07±9.88	0.73	18.03
Magnesium	mg/l	9.04±2.65	10.61±5.41	11.61±7.1	0.84	13.03
Sodium	mg/l	12.03±1.5	12.07±1.53	12.03±1.59	1	3.73
Potassium	mg/l	4.4±0.6	4.4±0.66	4.33±0.65	0.99	1.54
Silica	mg/l	42.8±6.95	46.4±6.95	46.03±9.11	0.83	18.75
Total Hardness	mg/l	76±15.1	70±3.46	78±8.72	0.63	24.87
Cal. Hardness	mg/l	38.77±4.16	26.32±20.41	30.23±24.76	0.72	45.26
Mag. Hardness	mg/l	37.23±11.02	43.7±22.37	47.77±29.23	0.85	53.75

4.3.4 Comparison between Chemical Parameters of TWP-A, TWP B and TWP-C

Table 9 presents the mean values of the chemical parameters under study in this research work for the three (3) sachets water producing companies. The data presented in the Table 9 indicate that mean values for all the chemical parameters achieved variation among the three different water samples under investigation, although some of the variations were found to be insignificant ($p < 0.05$). Therefore, with the exception of the variations discovered in total alkalinity, bicarbonate, nitrate, magnesium, total hardness and magnesium hardness, the variations within the rest were not significant ($p < 0.05$), though standard deviations were found to be wider in some cases (e.g. calcium hardness and silica). Thus, for total alkalinity, ANOVA Table in Appendix 2.4.2 shows that significant differences exist; hence, total alkalinity was found to be significantly higher in water produced, distributed and sold by TWP-C (76.67 mg/l) and lower in TWP-A (53.56 mg/l) at $p < 0.05$ ($p = 0.01$). Standard deviation ranged from 18.81 in

TWP-C to 11.22 in TWP-A. Again, bicarbonates in the water samples were discovered to be significantly [($p < 0.05$) in Appendix 2.4.3, $p = 0.02$] highest in TWP-C (93.56 mg/l), and lowest in TWP-A (65.34 mg/l); bicarbonate, levels for all the three water producers indicated that only TWP-B was not different significantly ($p < 0.05$) from the rest. Standard deviations of the bicarbonates ranged from 22.92 in TWP-C to 13.7 in TWP-A. Both total alkalinity and bicarbonate values were highly imprecise, and were widely and randomly distributed about the means. Appendix 2.4.6 shows that Nitrate values were significantly different ($p < 0.05$). LSD (Table 9) indicates that only TWP-B and TWP-C are not different among the three different producers ($p = 3 \times 10^{-5}$), with TWP-A recording the highest (8.13). The standard deviations for the different water producers indicate that replicate values were close to the mean, an indication of high precision. Magnesium values were also different at $p < 0.05$ ($p = 0.04$), such that TWPC again recorded the highest (10.42 mg/l); TWP-B was not different from the rest.

Moreover, total hardness was highest in TWP-C (74.67 mg/l), and these values were significant from their counterpart producers ($p = 0.0001$). It follows that, whiles the TWP-C recorded the highest mean values in almost all the parameters, especially where differences were significant, the replicate values of TWP-C were highly imprecise.

Table 9: Mean Chemical Parameters for TWP-A, TWP-B and TWP-C Compared

PARAMETER	UNIT	MANUFACTURERS			p-Value ($\alpha = 0.05$) 95% Confidence Interval	LSD
		TWP-A	TWP-B	TWP-C		
pH	pH-unit	6.92±0.27	7.1±0.18	7.11±0.21	0.15	0.36
Total Alkalinity	mg/l	53.56±11.22^{a}	58.11±12.31^{ab}	76.67±18.81^{b}	0.01	23
Bicarbonate	mg/l	65.34±13.7 ^{a}	70.31±14.95^{ab}	93.56±22.92 ^{b}	0.01	28
Sulphate	mg/l	3.83±1.37	3.34±0.85	3.09±1.16	0.39	1.83
Chloride	mg/l	6.99±0.71	6.78±2.39	8.31±0.5	0.07	2.35
Nitrate	mg/l	8.13±2.66 ^{a}	3.28±2.8 ^{b}	2.25±1.12 ^{b}	3×10^{-5}	3.73

Phosphate	mg/l	0.23±0.23	0.2±0.17	0.26±0.26	0.85	0.36
Fluoride	mg/l	0.6±0.06	0.6±0.06	0.63±0.32	0.93	0.31
Calcium	mg/l	12.18±2.67	12.5±2.38	12.62±6.78	0.98	7.1
Magnesium	mg/l	6.13±2.76 ^{a}	7.04±2.46^{ab}	10.42±4.79 ^{b}	0.04	4.11
Sodium	mg/l	11.21±1.11	11.34±0.99	12.04±1.33	0.28	1.85
Potassium	mg/l	6.59±9.91	4.71±0.46	4.38±0.55	0.68	9.19
Silica	mg/l	45.73±4.9	45.28±3.84	45.08±6.92	0.97	8.61
Total Hardness	mg/l	55.78±9.72 ^{a}	58.43±4.55 ^{a}	74.67±9.59 ^{b}	0.0001	13.32
Cal. Hardness	mg/l	30.52±6.73	31.89±6.00	31.77±17.09	0.96	17.88
Mag. Hardness	mg/l	25.26±11.35 ^{a}	28.42±9.73^{ab}	42.9±19.75 ^{b}	0.03	15.12

Means with the same letters are not different ($p < 0.05$)

4.4 Bacteriological Quality of Water Samples

4.4.1 Bacteriological Quality of Water Samples from TWP-A

The total colonies counted for *E. coli*, faecal coliforms, and total coliforms were estimated in their means for each manufacturer. For all manufacturers, total coliforms made up the majority of bacteria followed by faecal coliforms and *E. coli* being the least. For the TWP-A samples, colonies were identified in all three replicates of each of the producer, wholesale, and vendor samples (Table 10), but for TWP-B and TWP-C colonies were inconsistent among the sample points (Table 11 & 12).

For the TWP-A water samples, those from the vendors harboured the most bacteria whereas the producer samples contained the least bacteria. Generally, as observed for the TWP-A samples, the third replicates were least associated with bacterial growth whereas the second sampling showed the most bacterial growth (Appendix B and C). Total coliforms (10 cfu/100 ml) was the recorded lower mean count value in producer samples and (36 cfu/100 ml) in vendor samples was recorded as the highest mean count value. Although differences between the mean values were not significant at 5%, the standard deviations indicate that variations of the replicate values from the means were very wide, especially at the vendor point (33.06). For faecal coliform, the lower mean value count was (2.33 cfu/100 ml) in producer samples and its higher mean count value was (12.67 cfu/100 ml) in the vendor samples. Again, the vendor samples were ascertained to be highly imprecise in its replicate values (11.68) compared to (0.04) standard deviation recorded for the producer sample. The lowest mean count (1.33 cfu/100 ml) of *E. coli* was recorded in producer samples, and (3.33 cfu/100 ml) was the higher mean count recorded for vendor sample (Table 10).

Table 10: Bacteriological Parameters for TWP-A Samples

PARAMETER	UNIT	MEANS FOR TWP-A SAMPLE POINTS			P-VALUE ($\alpha = 0.05$) 95% confidence interval	LSD
		Factory	Wholesale	Vendor		
Total coliform	cfu/100 ml	10±7.55	11±9.54	36±33.06	0.28	49.28
Faecal coliform	cfu/100 ml	2.33±4.04	5.33±6.11	12.67±11.68	0.33	19.28
E. coli	cfu/100 ml	1.33±2.31	2.33±3.21	3.33±4.93	0.80	8.85

4.4.2 Bacteriological Quality of Water Samples from TWP-B

TWP-B water samples showed fair *E. coli* growth, and many of its replicate samples showed slight decrease in bacterial growth in vendor samples (Table 11). The lower total coliform mean value count recorded was 6.67 cfu/100 ml in producer and a higher mean value count of (10.33 cfu/100 ml) in vendor samples. A lower faecal coliform mean value count of 2.33 cfu/100 ml was found in the producer samples and a higher mean value count of 3 cfu/100 ml was recorded for the vendor samples (Table 11). For *E. coli*, higher mean value counts were (0.67 cfu/100 ml in both producer and wholesale samples and 0.33 cfu/100 ml was the lowest mean count which was recorded in vendor samples. The data shows that the counts for all the parameters for the different sample points were not significantly different ($p < 0.05$).

Table 11: Bacteriological Parameters for TWP-B Samples

PARAMETER	UNIT	MEANS FOR TWP-A SAMPLE POINTS			P-VALUE (α = 0.05) 95% confidence interval	LSD
		Factory	Wholesale	Vendor		
Total coliform	cfu/100 ml	6.67±7.02	6.33±9.29	10.33±7.64	0.80	19.48
Faecal coliform	cfu/100 ml	2.33±3.21	2.67±4.62	3.00±3.00	0.97	8.92
E.coli	cfu/100 ml	0.67±1.15	0.67±1.15	0.33±0.58	0.89	2.42

4.4.3 Bacteriological Quality of Water Samples from TWP-C

TWP-C water samples showed no *E. coli* growth, and many of its replicate samples showed no bacterial growth at all (Table 12). The total coliform mean count of 58.67 cfu/100 ml was the highest in producer samples and 3.33 cfu/100 ml was recorded as the lowest in wholesale and vendor samples. However, variations were ascertained to be pronounced in the standard deviations such that total coliform at the producer point was found to be significantly highest (98.17), compared with a standard deviation of 5.77 for both wholesale sample and vendor sample. On the other hand, faecal coliform mean count of 0.33 cfu/100 ml was recorded as the lowest for producer samples whiles 0.67 cfu/100 ml was recorded as the highest in both wholesale and vendor samples (Table

12). Replicate values were ascertained to be precise, the highest deviation being 1.15. Analysis of the variations showed that, none of the differences were significant

($p< 0.05$).

Table 12: Bacteriological Parameters for TWP-C Samples

PARAMETER	UNIT	MEANS FOR TWP-A SAMPLE POINTS	P-VALUE (α = 0.05)	LSD

		Factory	Wholesale	Vendor	95% confidence interval	
Total coliform	cfu/100 ml	58.67±98.17	3.33±5.77	3.33±5.77	0.43	137.81
Faecal coliform	cfu/100 ml	0.33±0.58	0.67±1.15	0.67±1.15	0.89	2.42
E.coli	cfu/100 ml	0±0.00	0±0.00	0±0.00	N/A	0

4.4.4 Comparison between Bacteriological Parameters of TWP-A, TWP-B and TWP-C

E. coli was the least prevalent of the bacteria in all sample sources for all manufacturers, followed by faecal coliforms. Among the manufacturers, TWP-B water samples were the most associated with bacterial growth; whereas, TWP-C water samples were found to contain the least bacterial growth. Subsequently, among the producer samples, TWP-A was the manufacturer with colonies in every sample. Moreover, TWP-B vendor samples always contained bacteria in higher levels compared to the producer and wholesale samples, except in the case of *E. coli* that producer and wholesale mean value counts were slightly lower than that of vendor mean count.

From Fig. 2, comparing all the bacteria sub-classifications, TWP-B water samples were associated with the narrowest range of mean growth between producer, wholesale, and vendor samples; similarly, the widest range of mean count growth was observed in TWP-C. The figure further indicates that among total coliforms were the highest bacterial entity in the water samples, such that the highest was found in the water produced by TWP-C (21.78 cfu/100 ml), followed by TWP-A (19.00 cfu/100 ml) and TWP-B (7.78 cfu/100 ml) respectively. Differences were found to be insignificant at $p < 0.05$ ($p=0.68$) [Table 13] among all the manufacturers; and standard deviations were also found to be very pronounced (56.49 for TWP-C, 21.75 for TWP-A, and 7.22 for TWP-B). Faecal coliforms were highest in TWP-A (6.78 cfu/100 ml) with a standard deviation of 8.29, whiles the lowest was recorded in TWP-C (0.56 cfu/100 ml) with a standard deviation of 0.88. TWP-C did not record the presence of any *E. coli*, whiles TWP-A and TWP-B recorded 2.33 cfu/100 ml and 0.56 cfu/100 ml respectively. Differences for both faecal coliform and *E. coli* were ascertained to be significant ($p <$ 0.05) (Table 13). Although, Appendices 3.4.1, 3.4.2 & 3.4.3 indicate that differences among the three companies for all the bacteriological parameters are not significant (p

<

0.05), the error bars (Fig. 2) constructed at α = 5 show that variations were very pronounced among all the companies for all the bacteriological parameters under study.

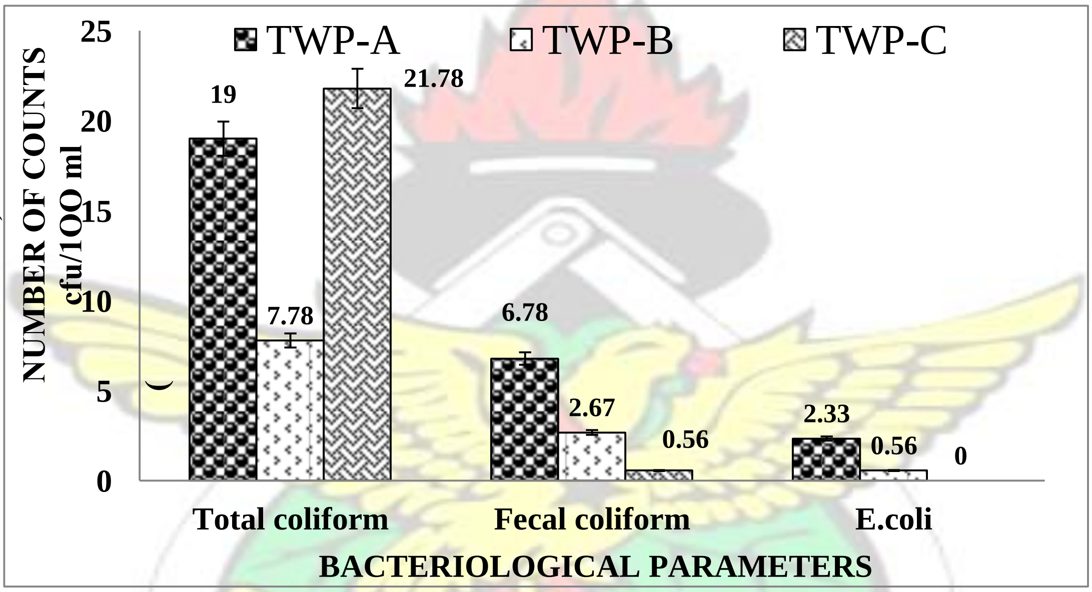

Figure 2: Comparison of Mean Bacteriological Parameters for TWP-A, TWP-Band TWP-C

Table 13: Comparison of Mean Bacteriological Parameters for TWP-A, TWP-B and TWP-C

PARAMETER	UNIT	MANUFACTURERS			P-VALUE (α = 0.05) 95% confidence interval	LSD
		TWP-A	TWP-B	TWP-C		
Total coliform	cfu/100 ml	19±21.75	7.78±7.22	21.78±56.49	0.68	56.41
Faecal coliform	cfu/100 ml	6.78±8.29	2.67±3.2	0.56±0.88	0.05	8.26
E.coli	cfu/100 ml	2.33±3.28	0.56±0.88	0±0.00	0.05	3.14

4.4.5 Summary of Microbial Results

For all the bacteria sub-classifications, TWP-B water samples were associated with the narrowest range of mean growth between producer, wholesale, and vendor samples. Similarly, the widest range of mean count growth was observed in TWP-C.

For the sampling points of the manufacturers, vendor points were associated with high bacteria growth whilst producer points were observed to have been associated with lower bacteria growth. Moreover; the vendor samples contributed the majority of the colonies whereas the producer samples contributed the least. Generally, the third replicates for the various sources were associated with the least bacteria as shown in (Table 10). Total coliform recorded the lower mean count with (3.33 cfu/100 ml) in the producer samples and (58.67 00cfu/100 ml) as the higher in vendor samples (Table 12). Faecal coliforms on the other hand recorded the lower mean count of (0.33 cfu/100 ml) in producer samples and (12.67cfu/100 ml) as the higher mean count in vendor samples (Table 10 & 12). *E. coli* was the least prevalent of bacteria in all the samples with a recorded lower mean count of (0.00 cfu/100 ml) in producer samples and a higher mean count of 3.33 cfu/100 ml) in vendor samples (Table 10 & 12).

4.5 Summary of Discussions

Water is said to be potable and deemed wholesome for consumption only when its physical, chemical and microbiological qualities conform to specified standards (Stoler, 2013). Consequently, one primary aim of the study was to compare the physical and chemical quality of sachet water from Tumu with those stipulated by GWCL and WHO. The Ghana Water Company (GWCL) adopts its water quality standards from the World Health Organization"s "Guidelines for Drinking-water Quality", both guidelines of which are used in this study. Some of the parameters have health implications and, therefore, their meeting of their respective guideline is critical; whereas other parameters have not been associated with any health risks and hence their quality requirements are either not stipulated, or are quite „flexible".

From the foregoing results and discussions, it follows, generally, that the levels of the various parameters were low for TWP-A water samples whereas TWP-B water samples in most cases were associated with a high mean for the various parameters (Table 14). Parameters for which no requirements are stipulated have been indicated with dashes. The specifications given are the permissible (threshold) limits and hence water samples are deemed to have met the requirement if the particular parameter exists in levels below the WHO guideline or GWCL standards stipulated.

Table 14: Water Samples Data Compared with WHO and GWCL Guidelines

PARAMETERS	UNIT	TWP-A	TWP-B	TWP-C	WHO	GWCL
PHYSICAL PARAMETERS						
TDS	mg/l	98.48	129.06	97.71	**1000**	**1000**
Conductivity	µs/cm	164.44	213.33	181.13	**300**	**-**
Colour	Hz	2.50	2.50	2.50	**15**	**0-15**
Turbidity	NTU	1.55	1.88	1.66	**5**	**0- 5**
Temperature	^{o}C	27.16	27.44	27.63	**-**	**-**
CHEMICAL PARAMETERS						
pH	pH-unit	6.92	7.10	7.09	**6.5-8.5**	**0-10**
Total Alkalinity	mg/l	53.56	76.66	58.11	**-**	**-**
Bicarbonate	mg/l	65.34	93.55	70.31	**-**	**-**
Sulphate	mg/l	3.82	3.08	3.34	**400**	**0-400**
Chloride	mg/l	6.98	8.31	6.77	**250**	**0-600**
Nitrate	mg/l	8.13	2.25	3.27	**10**	**0-10**
Phosphate	mg/l	0.23	0.26	0.20	**-**	**-**
Fluoride	mg/l	0.60	0.62	0.59	**1.5**	**0-1.5**
Calcium	mg/l	12.18	12.62	12.50	**200**	**-**
Magnesium	mg/l	6.12	10.41	7.03	**150**	**-**
Sodium	mg/l	11.21	12.04	11.34	**200**	**-**
Potassium	mg/l	6.58	4.37	4.71	**30**	**-**
Silica	mg/l	45.73	45.07	45.27	**-**	**-**
Total Hardness	mg/l	55.77	74.66	58.43	**500**	**0-500**
Cal. Hardness	mg/l	30.52	31.77	31.88	**-**	**-**

Mag. Hardness	mg/l	25.26	42.90	28.42	**-**	**-**
BACTERIOLOGICAL PARAMETERS						
Total coliform	cfu/100 ml	19.00	6.33	21.77	**0**	**-**
Faecal coliform	cfu/100 ml	6.77	2.66	0.55	**0**	**-**
E. coli	cfu/100 ml	2.33	0.55	0	**0**	**-**

From the various WHO and GWCL water quality guidelines, all physico-chemical parameters were far below the WHO stipulated standards, and were within the GWCL recommended range. Generally, the physico-chemical parameters of manufacturers were within the permissible limits as evident from (Table 14). However, microbial mean counts for all manufacturers were above WHO guideline and GWCL standards of zero (0 cfu/100 ml) except for *E. coli* in TWP-C samples (Table 14).

4.5.1 Summary Discussion on the Physico-Chemical Qualities of the Water Samples

Physico-chemical properties of each sample were assessed using several parameters, with the goal of comparing with the water quality requirements as stipulated by the Ghana Water Company Limited (GWCL) and World Health Organization (WHO) guideline values. Various physico-chemical parameters are used as indicators of water quality, and some of them have health implications should they exist in inordinate amounts in drinking water.

Comparison of the levels of the various physico-chemical parameters between the producers, wholesalers and vendor samples, first for each manufacturer and then the total pooled data, showed significant differences existed for TDS, conductivity, total alkalinity, bicarbonate, nitrate, total hardness and magnesium hardness ($p < 0.05$). Levels of the parameters as far the different sources were concerned for each manufacturer were hence comparable. Generally, levels of parameters of all three manufacturers were below (WHO) guideline values and (GWCL) standards, but between them there were variations in values of parameters.

The results showed that only data for silica was statistically different in TWP-B, whiles in TWP-C only sulphate values were significantly different between the three sample points (factory, wholesaler and vendor). The trend could be attributed to the unhygienic condition of bagged sachet and vendering strategies that exposes the water to recontamination. This trend was, however, not unexpected for the parameters in question easily click to pipelines during production, reducing their availability for the water. Again, Haas, Meyer and Paller (1983) indicated that water deteriorates in quality during distribution, which could account for the reduction in quality along the distribution chain. In a recent study by Duwiejuah (2013), no significant differences in levels of the physico-chemical parameters were observed for water samples stored in different conditions (ambient, refrigerator, sun) over a 3-month period. Nonetheless, over an extended period of time, Akinde, Nwachukwu and Ogamba (2011) reported that the levels of the parameters have been posited to deteriorate, affecting the overall aesthetic quality of the water. For the samples in the study, it is possible that the time window from manufacture of the sachet waters to the vendor is not too long enough to cause major differences in the levels of the various parameters.

When all data was pooled together for each manufacturer and comparisons were made, statistical differences ($p<0.05$) were observed in only TDS and conductivity for physical parameters, and total alkalinity, bicarbonate, nitrate, total hardness and magnesium hardness. Physical parameters like colour, turbidity, and temperature were almost the same across all the manufacturers; the reason could be attributed to the relative ambient, hygienic level of sachet bags and storage facilities within which water was stored. TWP-C water samples were consistently observed with the highest levels of physico-chemical parameters, whereas TWP-A water samples were associated with the lowest levels.

The trend was the same for comparisons between the sample points, when all producers were compared: for each parameter, levels were different across manufacturers and in some cases the differences were significant. Onweluzo and Akuagbazie (2010) suggested that such disparities in level of water quality parameters between different sampled manufacturers were not unexpected. Usually, the differences could be imputed to the possible differences in water sources, and the likely different treatment approaches and technologies used by different manufacturers giving rise to water of varying levels of the parameters. Okoiga (2007) agrees with this assertion when he stated that minimum water treatment requirements as stipulated by the Ghana Food and Drugs Authority (FDA), which includes filtration by at least five filters (cartridges to be changed every three months) followed by UV disinfection with one UV unit per machine, are not followed by many manufacturers.

This means manufacturers have flexibility with regard to the number of filters and UV units, meaning treated water quality will vary with different manufacturers. For any two manufacturers applying exactly the same treatment systems, quality of the final treated water from each manufacturer will be determined by differences in the source water quality (Stoler, 2012). In Ghana, Ahimah and Ofosu (2012) indicated that likely sources of water for the Sachet water industry are the Ghana Water Company, hand-dug wells, and mechanised boreholes, and these have significant effects on the quality of the final product. Consequently, the minor differences in analysed parameters with respect to the manufacturers could be attributed to these different sources.

pH is one such parameters with flexible requirement as no health based guideline really exists for it. Nonetheless, a range of 6.5 – 8.5 is often quoted (WHO Standards, Table 14). Levels of pH below this range are deemed too acidic for body processes whereas levels above are deemed too alkaline for consumption (Ndamitso, Idris, Likita, Tijani, Ajai & Bala, 2013). All samples for all manufacturers were hence within the pH permissible range.

Total dissolved solid is a measure of the level of dissolved solids in water and it influences the overall taste of drinking water (Onweluzo & Akuagbazie, 2010). TDS is, however, not a health based parameter hence it has a flexible permissible limit of 1000 mg/l as stipulated by both the WHO and GWCL. The highest TDS level was found in manufacturer TWP-C (137.2 mg/l); which is clearly below the WHO and GWCL limits and within the acceptable range (WHO Standards, Table 14).

Conductivity, with a permissible limit of 300 µs/cm, is closely related to TDS and hence all water samples conformed to this specification. Two physical parameters that inform the aesthetic appreciation of water are turbidity and colour, and in all instances, water samples met their respective specifications with regard to the two parameters. No permissible limit value is set of total alkalinity but very high levels above 300 mg/l have been suggested to result in water with a flat and unpleasant taste (Ackah *et al.*, 2012). All water samples from the study, however, were within moderate and tolerable levels of total alkalinity.

Sulphate has also been associated with laxative effects, especially when a switch from water of low sulphate to one of high sulphate level is made (Ndamitso *et al.*, 2013). The highest value recorded for sulphates was 3.82 mg/l, and this was far below the accepted minimum standard of 400 mg/l but was within the GWCL range.

For chlorides, the highest value was 8.31 mg/l, far below the stipulated 250 mg/l by WHO but within the GWCL range (Table 14).

Two of the health based water parameters that were determined in the study were fluoride and nitrate. Within its permissible range of 0 – 1.5 mg/l, fluoride is critical for a good dental health. Very low fluoride levels (less than 0.2 mg/l) depending on the locality may be deemed inadequate, whereas continued consumption of very high levels (more than 4.0 mg/l) could result in dental fluorosis and even skeletal fluorosis in very extreme cases of overexposure (Dissanayake, 1991).

Calcium and magnesium are considered essential nutrients in water and hence a moderate amount of both are desirable in water. However, too much of both ions tend to affect the hardness of water (Ndamitso *et al*., 2013).

Other non-health based chemical parameters that were within their stipulated permissible limits include sodium (maximum recorded: 12.04mg/l), potassium (maximum recorded: 6.58 mg/l), calcium (maximum recorded: 12.62 mg/l), magnesium (maximum recorded: 10.42 mg/l), and silica (maximum recorded: 45.73 mg/l), as indicated by the WHO and GWCL standards in (Table 14).

Since total hardness gives indication about the palatability of water, it was conducted as the last physico-chemical assessment. It has been suggested that hardness of water can be attributed to high magnesium and calcium levels (Dodoo, Quagraine, Okai-Sam, Kambo & Headley, 2006). Total hardness, calcium hardness and magnesium hardness were identified with varying levels, which were significant in the total hardness and magnesium hardness. There is no stipulated WHO or GWCL standard for the total hardness, calcium hardness and magnesium hardness (Table 14).

Generally, it can be deduced that the physico-chemical properties of the water samples are acceptable and none should pose any health or other threats to consumers.

4.5.2 Summary Discussion on Microbial Quality of the Water Samples

Bacteriological quality of water is very important so far as water quality is concerned. This is because portable water standards stipulated by both WHO and the GWCL peg all microbial entities at 0.00 cfu/100 ml. Therefore, in potable water quality assessment pre-eminence is given to microbial quality, especially because of their possible health implications. Drinking water, if not well treated, has the ability to transmit harmful pathogens that can cause diseases and, as a result, the microbial quality of water is of concern to all: consumers, regulatory bodies and public health authorities (Addo-Fordjour, Anning, Larbi & Akyeampong, 2009).

Packaged water has been implicated as the source of outbreaks of various infections like typhoid and cholera in all countries at different levels of economic development, and in Ghana a host of studies have been conducted on their bacteriological quality. The coliform group of bacteria is the most frequently used indicator of water bacteriological quality and comprises bacteria with defined biochemical and growth characteristics (OECD, 2003).

Total coliforms represent the whole group (bacteria that multiply at 37 ^{o}C), thermotolerant coliforms describe those that grow at a higher temperature (44 ^{o}C), and *E. coli* is thermotolerant type that is of faecal origin. Any indication that a water sample leaving a treatment system contains any of these bacteria will require immediate attention (OECD, 2003).

For all the manufacturers in the study, the highest contribution to bacterial growth was by total coliforms. Normally, since bacteria classified under this umbrella are not from faecal origin, they can exist in natural water and hence their occasional presence can be tolerated in untreated and piped water. However, their detection in treated water cannot be tolerated and the WHO stipulates that drinking water contains no total coliforms at all. Thermo tolerant (faecal) coliforms were the next to contribute to the high bacterial growth in water samples. Just like for total coliforms, their appearance in a treated water sample is indicative of inadequate treatment and corrective measures must be adopted immediately in such cases. *E. coli* is the more definitive indicator of faecal contamination.

A plethora of studies conducted in different parts of the country have in one way or the other made similar observations of poor bacteriological quality of sachet water. Notable ones include those by Obiri-Danso *et al.* (2003), Dodoo *et al.* (2006), Ampofo, Andoh, Tetteh and Bello (2008), Okoiga (2007) and Duwiejuah, Cobbina and Akrong (2013), Kwakye-Nuako, Borketey, Mensah-Attipoe, Asmah and Ayeh-Kumi (2007), Addo, Mensah, Bekoe, Bonsu and Akyeh (2009a), Odonkor and Addo (2013) and (Osei, Newman, Mingle, Ayeh-Kumi & Kwasi, 2013).

Primarily, the bacterial contamination observed in water samples in the study could emanate from the type of untreated water used for production (Oyedeji, Olutiola & Moninuola, 2010), in which case water sourced from shallow underground wells will require more vigorous treatment compared to water sourced from pre-treated sources. Bacteria could also abound in the filter system which would make contamination of treated water possible and this is why the FDA requires the cartridges of the filter to be changed every three months (Addo-Fordjour *et al*., 2009). Other factors like poor sterilization of plastic bags used to package the water, and generally unhygienic production environment as well as poor plant sanitation have all been observed (Osei *et al.*, 2013). Generally, these issues are easily checked with proper monitoring mechanisms for sachet water manufacturers by regulatory bodies. However, it is public perception that the sachet water business in Ghana is replete with an astounding number of unregistered and illegal manufacturers that monitoring of their operations by the Food and Drug"s Authority is near to impossible.

The above enumerated causes of contamination will account for the presence of bacteria found in all factory water samples in this study. However, they may or may not account for the presence of bacteria in the wholesaler and vendor samples, as the bacteria infection could possibly have taken place after the samples left the producer. It follows that, low residual purifier like chlorine in the packaged water could account for the increased coliform counts in the wholesaler and the vendor points. Thus, as water keeps long in the package, the residual treatment chemicals are continuously depleted towards the expiry dates, whiles microbial biofilms multiply, greatly compromising the water quality. Tables 10, 11 and 12 indicates the general trend of increased microbial counts from the producer to the vendor, with the exception of total coliform count for TWP-C where the producer counts were the highest (even for the entire microbial entities under study). Holding on to the „contamination at producer‟ theory (Hogan, 1970), then this trend of result would mean that bacteriological levels worsen with time, as normally the sachet water bags are bound to take some time to get to the vendor after leaving the producer. In a study conducted in Lagos, Omalu, Olayemi, Gbesi, Adeniran, Ayanwale, Mohammed and Chukwuemeka (2010) observed this phenomenon of bacteriological quality deteriorating with time.

CHAPTER FIVE

CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions

This study determined both the physico-chemical and bacteriological quality of sachet water from three manufacturers in the Tumu Township. Generally, the physicochemical parameters of all sachet water samples from three manufacturers were within the Ghana Water Company and the World Health Organization specified limits. Generally, within the same manufacturer, samples did not exhibit significant differences in physico-chemical parameters between producer, wholesaler and vendor samples, but, differences were observed as far as comparison between different manufacturers was concerned.

Generally, coliforms were enumerated in almost all the water samples for three manufacturers and per the WHO guidelines; the bacteriological quality of the water samples was high. Specifically, vendor water samples contained the highest growths of total and faecal coliforms as well as *E. coli,* whereas factory samples contained the least growth of the bacteria. TWP-A samples were the most contaminated, whereas TWP-C samples were the least contaminated and did not contain any *E. coli* growths at all.

Overall, the bacteriological quality of sachet water from the three manufacturers was high and they could pose a health threat for consumers, especially those who patronize TWP-A Sachet water.

5.2 Recommendations Based on Study Findings

Based on results from the study, it is recommended that factory-bagged sachets of drinking water sold in Ghana should be continuously monitored at producer, wholesaler and vendor locations for microbiological contamination, with the aim of raising standards in the industry and re-assuring the public of safe sachet water supply on the market for consumption.

Refrigerated storage of drinking water products should be encouraged, as this will minimise bacterial multiplication from time to time. Each product should also be marked with the production date, expiry date and batch number for easy tracking in case of contamination.

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APPENDICES

APPENDIX 1: ANOVA FOR PHYSICAL PROPERTIES OF THE WATER SAMPLES

Appendix 1.1: ANOVA for Physical Properties of the Water Samples from TWPA

Appendix 1.1.1: ANOVA for TDS of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Sample Points	20.11556	2	10.05778	0.347993	0.719466	5.143253
Within Groups	173.4133	6	28.90222			
Total	193.5289	8				

Appendix 1.1.2: ANOVA for Conductivity of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	57.20889	2	28.60444	0.322744	0.735992	5.143253
Within Groups	531.7733	6	88.62889			
Total	588.9822	8				

Appendix 1.1.3: ANOVA for Colour of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0	2	0	65535	#DIV/0!	5.143253
Within Groups	0	6	0			
Total	0	8				

Appendix 1.1.4: ANOVA for Turbidity of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.222222	2	0.111111	0.333333	0.729	5.143253
Within Groups	2	6	0.333333			
Total	2.222222	8				

Appendix 1.1.5: ANOVA for Temperature of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0	2	0	0	1	5.143253
Within Groups	20.28	6	3.38			
Total	20.28	8				

Appendix 1.2: ANOVA for Physical Properties of the Water Samples from TWP-B

Appendix 1.2.1: ANOVA for TDS of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2341.602	2	1170.801	1.199512	0.364559	5.143253
Within Groups	5856.387	6	976.0644			
Total	8197.989	8				

Appendix 1.2.2: ANOVA for Conductivity of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	7.94	2	3.97	0.108539	0.898866	5.143253
Within Groups	219.46	6	36.57667			
Total	227.4	8				

Appendix 1.2.3: ANOVA for Colour of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0	2	0	65535	#DIV/0!	5.143253
Within Groups	0	6	0			
Total	0	8				

Appendix 1.2.4: ANOVA for Turbidity of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.666667	2	0.333333	1.5	0.296296	5.143253
Within Groups	1.333333	6	0.222222			
Total	2	8				

Appendix 1.2.5: ANOVA for Temperature of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.626667	2	0.813333	0.305127	0.747824	5.143253
Within Groups	15.99333	6	2.665556			
Total	17.62	8				

Appendix 1.3: ANOVA for Physical Properties of the Water Samples from TWPC

Appendix 1.3.1: ANOVA for TDS of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.92	2	1.96	0.03311	0.967608	5.143253
Within Groups	355.18	6	59.19667			
Total	359.1	8				

Appendix 1.3.2: ANOVA for Conductivity of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	34.66667	2	17.33333	0.15087	0.863122	5.143253
Within Groups	689.3333	6	114.8889			
Total	724	8				

Appendix 1.3.3: ANOVA for Turbidity of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0	2	0	65535	#DIV/0!	5.143253
Within Groups	0	6	0			
Total	0	8				

Appendix 1.3.4: ANOVA for Colour of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.222222	2	0.111111	0.25	0.786527	5.143253
Within Groups	2.666667	6	0.444444			
Total	2.888889	8				

Appendix 1.3.5: ANOVA for Temperature of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.062222	2	0.031111	0.006406	0.993621	5.143253
Within Groups	29.14	6	4.856667			
Total	29.20222	8				

Appendix 1.4: ANOVA for Physical Properties of the Water Samples from TWP-A, TWP-B and TWP-C Compared

Appendix 1.4.1: ANOVA for Comparison of TDS of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	5756.329	2	2878.164	7.893837	0.00232	3.4028261
Error/Residuals	8750.618	24	364.6091			
Total	14506.95	26				

Appendix 1.4.2: ANOVA for Comparison of Conductivity of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	11116.45	2	5558.224	86.60017	1.06E-11	3.4028261
Error/Residuals	1540.382	24	64.18259			
Total	12656.83	26				

Appendix 1.4.3: ANOVA for comparison of Colour of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	0	2	0	65535	#DIV/0!	3.4028261
Error/Residuals	0	24	0			
Total	0	26				

Appendix 1.4.4: ANOVA for Comparison of Turbidity of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	0.518519	2	0.259259	0.875	0.429742	3.4028261
Error/Residuals	7.111111	24	0.296296			
Total	7.62963	26				

Appendix 1.4.5: ANOVA for Comparison of Temperature of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	0.991852	2	0.495926	0.177374	0.838554	3.4028261
Error/Residuals	67.10222	24	2.795926			
Total	68.09407	26				

APPENDIX 2: ANOVA FOR CHEMICAL PROPERTIES OF THE WATER SAMPLES

Appendix 2.1: ANOVA for Chemical Properties of the Water Samples from TWP-A

Appendix 2.1.1: ANOVA for pH of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.001689	2	0.000844	0.008995	0.991059	5.143253
Within Groups	0.563267	6	0.093878			
Total	0.564956	8				

Appendix 2.1.2: ANOVA for Total Alkalinity of the Water Samples from TWPA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	118.2222	2	59.11111	0.399399	0.687317	5.143253
Within Groups	888	6	148			
Total	1006.222	8				

Appendix 2.1.3: ANOVA for Bicarbonate of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	176.8089	2	88.40444	0.400699	0.686529	5.143253
Within Groups	1323.753	6	220.6256			
Total	1500.562	8				

Appendix 2.1.4: ANOVA for Sulphates of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.473622	2	0.736811	0.328084	0.732455	5.143253
Within Groups	13.4748	6	2.2458			
Total	14.94842	8				

Appendix 2.1.5: ANOVA for Chlorides of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit

Between Groups	0.667222	2	0.333611	0.5999	0.578752	5.143253
Within Groups	3.336667	6	0.556111			
Total	4.003889	8				

Appendix 2.1.6: ANOVA for Nitrates of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.7686	2	0.3843	0.041167	0.959938	5.143253
Within Groups	56.0114	6	9.335233			
Total	56.78	8				

Appendix 2.1.7: ANOVA for Phosphates of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.1382	2	0.0691	1.507669	0.294787	5.143253
Within Groups	0.274994	6	0.045832			
Total	0.413194	8				

Appendix 2.1.8: ANOVA for Fluorides of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.008867	2	0.004433	1.64876	0.268752	5.143253
Within Groups	0.016133	6	0.002689			
Total	0.025	8				

Appendix 2.1.9: ANOVA for Calcium of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8.629422	2	4.314711	0.535053	0.61119	5.143253
Within Groups	48.38453	6	8.064089			
Total	57.01396	8				

Appendix 2.1.10: ANOVA for Magnesium of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	14.31242	2	7.156211	0.923945	0.446884	5.143253
Within Groups	46.47167	6	7.745278			
Total	60.78409	8				

Appendix 2.1.11: ANOVA for Sodium of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.055556	2	0.027778	0.01688	0.983308	5.143253

Within Groups	9.873333	6	1.645556			
Total	9.928889	8				

Appendix 2.1.12: ANOVA for Potassium of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	196.6822	2	98.34111	1.002276	0.421156	5.143253
Within Groups	588.7067	6	98.11778			
Total	785.3889	8				

Appendix 2.1.13: ANOVA for Silica of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	15.04667	2	7.523333	0.254865	0.783005	5.143253
Within Groups	177.1133	6	29.51889			
Total	192.16	8				

Appendix 2.1.14: ANOVA for Total Hardness of the Water samples from TWPA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	67.55556	2	33.77778	0.294574	0.755033	5.143253
Within Groups	688	6	114.6667			
Total	755.5556	8				

Appendix 2.1.15: ANOVA for Calcium Hardness of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	54.80222	2	27.40111	0.535155	0.611137	5.143253
Within Groups	307.2133	6	51.20222			
Total	362.0156	8				

Appendix 2.1.16: ANOVA for Magnesium Hardness of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	243.4815	2	121.7407	0.927259	0.445754	5.143253
Within Groups	787.7462	6	131.291			
Total	1031.228	8				

Appendix 2.2: ANOVA for Chemical Properties of the Water Samples from TWP-B

Appendix 2.2.1: ANOVA for pH of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.006422	2	0.003211	0.074851	0.928734	5.143253
Within Groups	0.2574	6	0.0429			
Total	0.263822	8				

Appendix 2.2.2: ANOVA for Total Alkalinity of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	106.8889	2	53.44444	0.289934	0.758232	5.143253
Within Groups	1106	6	184.3333			
Total	1212.889	8				

Appendix 2.2.3: ANOVA for Bicarbonate of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	162.0689	2	81.03444	0.299079	0.751944	5.143253
Within Groups	1625.68	6	270.9467			
Total	1787.749	8				

Appendix 2.2.4: ANOVA for Sulphates of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.844867	2	1.422433	2.946284	0.128418	5.143253
Within Groups	2.896733	6	0.482789			
Total	5.7416	8				

Appendix 2.2.5: ANOVA for Chlorides of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.186667	2	0.093333	0.012346	0.987755	5.143253
Within Groups	45.35913	6	7.559856			
Total	45.5458	8				

Appendix 2.2.6: ANOVA for Nitrates of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.632289	2	0.316144	0.030471	0.970137	5.143253
Within Groups	62.25107	6	10.37518			
Total	62.88336	8				

Appendix 2.2.7: ANOVA for Phosphates of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit

Between Groups	0.0222	2	0.0111	0.306777	0.746705	5.143253
Within Groups	0.217096	6	0.036183			
Total	0.239296	8				

Appendix 2.2.8: ANOVA for Fluorides of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.008089	2	0.004044	1.263889	0.348294	5.143253
Within Groups	0.0192	6	0.0032			
Total	0.027289	8				

Appendix 2.2.9: ANOVA for Calcium of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	7.806667	2	3.903333	0.626315	0.566197	5.143253
Within Groups	37.39333	6	6.232222			
Total	45.2	8				

Appendix 2.2.10: ANOVA for Magnesium of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.492022	2	1.246011	0.16296	0.853262	5.143253
Within Groups	45.87667	6	7.646111			
Total	48.36869	8				

Appendix 2.2.11: ANOVA for Sodium of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.002222	2	0.001111	0.000859	0.999141	5.143253
Within Groups	7.76	6	1.293333			
Total	7.762222	8				

Appendix 2.2.12: ANOVA for Potassium of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.015556	2	0.007778	0.027237	0.97325	5.143253
Within Groups	1.713333	6	0.285556			
Total	1.728889	8				

Appendix 2.2.13: ANOVA for Silica of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit

Between Groups	87.28222	2	43.64111	8.553354	0.017508	5.143253
Within Groups	30.61333	6	5.102222			
Total	117.8956	8				

Appendix 2.2.14: ANOVA for Total Hardness of the Water samples from TWPB

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	11.64667	2	5.823333	0.226481	0.803853	5.143253
Within Groups	154.2733	6	25.71222			
Total	165.92	8				

Appendix 2.2.15: ANOVA for Calcium Hardness of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	66.28222	2	33.14111	0.898268	0.455773	5.143253
Within Groups	221.3667	6	36.89444			
Total	287.6489	8				

Appendix 2.2.16: ANOVA for Magnesium Hardness of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	56.14222	2	28.07111	0.240282	0.793625	5.143253
Within Groups	700.9533	6	116.8256			
Total	757.0956	8				

Appendix 2.3: ANOVA for Chemical Properties of the Water Samples from TWP-C

Appendix 2.3.1: ANOVA for pH of the water samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.008867	2	0.004433	0.07444	0.929107	5.143253
Within Groups	0.357333	6	0.059556			
Total	0.3662	8				

Appendix 2.3.2: ANOVA for Total Alkalinity of the Water Samples from TWPC

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	74.66667	2	37.33333	0.081238	0.922971	5.143253
Within Groups	2757.333	6	459.5556			
Total	2832	8				

Appendix 2.3.3: ANOVA for Bicarbonate of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	105.9756	2	52.98778	0.077574	0.926272	5.143253
Within Groups	4098.387	6	683.0644			
Total	4204.362	8				

Appendix 2.3.4: ANOVA for Sulphates of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	7.268156	2	3.634078	6.265531	0.033943	5.143253
Within Groups	3.480067	6	0.580011			
Total	10.74822	8				

Appendix 2.3.5: ANOVA for Chlorides of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.660022	2	0.330011	1.483492	0.299581	5.143253
Within Groups	1.334733	6	0.222456			
Total	1.994756	8				

Appendix 2.3.6: ANOVA for Nitrates of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.098289	2	0.049144	0.02945	0.971119	5.143253
Within Groups	10.01253	6	1.668756			
Total	10.11082	8				

Appendix 2.3.7: ANOVA for Phosphates of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.105	2	0.0525	0.705734	0.530568	5.143253
Within Groups	0.446344	6	0.074391			
Total	0.551344	8				

Appendix 2.3.8: ANOVA for Fluorides of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.116222	2	0.058111	0.492587	0.633756	5.143253
Within Groups	0.707826	6	0.117971			
Total	0.824048	8				

Appendix 2.3.9: ANOVA for Calcium of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit

Between Groups	35.94889	2	17.97444	0.324696	0.734697	5.143253
Within Groups	332.1467	6	55.35778			
Total	368.0956	8				

Appendix 2.3.10: ANOVA for Magnesium of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	10.07362	2	5.036811	0.174257	0.844185	5.143253
Within Groups	173.4267	6	28.90446			
Total	183.5004	8				

Appendix 2.3.11: ANOVA for Sodium of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.002222	2	0.001111	0.000468	0.999532	5.143253
Within Groups	14.24	6	2.373333			
Total	14.24222	8				

Appendix 2.3.12: ANOVA for Potassium of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.008889	2	0.004444	0.010989	0.989091	5.143253
Within Groups	2.426667	6	0.404444			
Total	2.435556	8				

Appendix 2.3.13: ANOVA for Silica of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	23.54889	2	11.77444	0.196532	0.826659	5.143253
Within Groups	359.4667	6	59.91111			
Total	383.0156	8				

Appendix 2.3.14: ANOVA for Total Hardness of the Water Samples from TWPC

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	104	2	52	0.493671	0.633166	5.143253
Within Groups	632	6	105.3333			
Total	736	8				

Appendix 2.3.15: ANOVA for Calcium Hardness of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	243.1606	2	121.5803	0.348458	0.719166	5.143253
Within Groups	2093.455	6	348.9092			
Total	2336.616	8				

Appendix 2.3.16: ANOVA for Magnesium Hardness of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	169.3067	2	84.65333	0.172024	0.845969	5.143253
Within Groups	2952.613	6	492.1022			
Total	3121.92	8				

Appendix 2.4: ANOVA for Chemical Properties of the Water Samples from TWP-A, TWP-B and TWP-C Compared

Appendix 2.4.1: ANOVA for comparison of pH of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	0.202222	2	0.101111	2.030721	0.153185	3.4028261
Error/Residuals	1.194978	24	0.049791			
Total	1.3972	26				

Appendix 2.4.2: ANOVA for comparison of Total Alkalinity of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	2697.556	2	1348.778	6.408623	0.005887	3.4028261
Error/Residuals	5051.111	24	210.463			
Total	7748.667	26				

Appendix 2.4.3: ANOVA for comparison of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	4082.516	2	2041.258	6.538413	0.005411	3.4028261
Error/Residuals	7492.673	24	312.1947			
Total	11575.19	26				

Appendix 2.4.4: ANOVA for comparison of Sulphates of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	2.544319	2	1.272159	0.971168	0.39303	3.4028261
Error/Residuals	31.43824	24	1.309927			
Total	33.98256	26				

Appendix 2.4.5: ANOVA for comparison of Chlorides of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	12.46254	2	6.23127	2.901389	0.07438	3.4028261
Error/Residuals	51.54444	24	2.147685			
Total	64.00699	26				

Appendix 2.4.6: ANOVA for comparison of Nitrates of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	177.3403	2	88.67014	16.39836	3.24E-05	3.4028261
Error/Residuals	129.7742	24	5.407257			
Total	307.1145	26				

Appendix 2.4.7: ANOVA for Comparison of Phosphates of the Water Samples from TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	0.016267	2	0.008133	0.162149	0.851239	3.4028261
Error/Residuals	1.203834	24	0.05016			
Total	1.220101	26				

Appendix 2.4.8: ANOVA for comparison of Fluorides of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	0.005486	2	0.002743	0.07512	0.92785	3.4028261
Error/Residuals	0.876337	24	0.036514			
Total	0.881823	26				

Appendix 2.4.9: ANOVA for comparison of Calcium of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	0.928563	2	0.464281	0.023692	0.976609	3.4028261
Error/Residuals	470.3095	24	19.59623			
Total	471.2381	26				

Appendix 2.4.10: ANOVA for comparison of Magnesium of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	91.91867	2	45.95934	3.769049	0.037715	3.4028261

Error/Residuals	292.6531	24	12.19388			
Total	384.5718	26				

Appendix 2.4.11: ANOVA for Comparison of Sodium of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	3.606667	2	1.803333	1.355324	0.276899	3.4028261
Error/Residuals	31.93333	24	1.330556			
Total	35.54	26				

Appendix 2.4.12: ANOVA for Comparison of Potassium of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	25.57852	2	12.78926	0.388754	0.682093	3.4028261
Error/Residuals	789.5533	24	32.89806			
Total	815.1319	26				

Appendix 2.4.13: ANOVA for Comparison of Silica of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	2.031852	2	1.015926	0.03518	0.965481	3.4028261
Error/Residuals	693.0711	24	28.87796			
Total	695.103	26				

Appendix 2.4.14: ANOVA for comparison of Total Hardness of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	1882.09	2	941.0448	13.62619	0.000111	3.4028261
Error/Residuals	1657.476	24	69.06148			
Total	3539.565	26				

Appendix 2.4.15: ANOVA for comparison of Calcium Hardness of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	10.33167	2	5.165833	0.041517	0.959402	3.4028261
Error/Residuals	2986.28	24	124.4283			
Total	2996.612	26				

Appendix 2.4.16: ANOVA for Comparison of Magnesium Hardness of the Water

Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	1592.187	2	796.0936	3.8911	0.034382	3.4028261
Error/Residuals	4910.243	24	204.5935			
Total	6502.43	26				

APPENDIX 3: ANOVA FOR BACTERIOLOGICAL PROPERTIES OF THE WATER SAMPLES

Appendix 3.1: ANOVA for Bacteriological Properties of the Water Samples from TWP-A

Appendix 3.1.1: ANOVA for Total Coliforms of the Water Samples from TWPA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1302	2	651	1.573731	0.282197	5.143253
Within Groups	2482	6	413.6667			
Total	3784	8				

Appendix 3.1.2: ANOVA for Faecal Coliforms of the Water Samples from TWPA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	169.5556	2	84.77778	1.338596	0.33061	5.143253
Within Groups	380	6	63.33333			
Total	549.5556	8				

Appendix 3.1.3: ANOVA for E. coli of the Water Samples from TWP-A

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6	2	3	0.225	0.804961	5.143253
Within Groups	80	6	13.33333			
Total	86	8				

Appendix 3.2: ANOVA for Bacteriological Properties of the Water Samples from TWP-B

Appendix 3.2.1: ANOVA for Total Coliforms of the water samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	29.55556	2	14.77778	0.228522	0.802329	5.143253
Within Groups	388	6	64.66667			
Total	417.5556	8				

Appendix 3.2.2: ANOVA for Faecal Coliforms of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.666667	2	0.333333	0.02459	0.975808	5.143253
Within Groups	81.33333	6	13.55556			
Total	82	8				

Appendix 3.2.3: ANOVA for E. coli of the Water Samples from TWP-B

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.222222	2	0.111111	0.111111	0.896638	5.143253
Within Groups	6	6	1			
Total	6.222222	8				

Appendix 3.3: ANOVA for Bacteriological Properties of the Water Samples from TWP-C

Appendix 3.3.1: ANOVA for Total Coliforms of the Water Samples from TWPC

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6123.556	2	3061.778	0.946551	0.439249	5.143253
Within Groups	19408	6	3234.667			
Total	25531.56	8				

Appendix 3.3.2: ANOVA for Faecal Coliforms of the Water Samples from TWPC

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.222222	2	0.111111	0.111111	0.896638	5.143253
Within Groups	6	6	1			
Total	6.222222	8				

Appendix 3.3.3: ANOVA for E. coli of the Water Samples from TWP-C

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0	2	0	65535	#DIV/0!	5.143253
Within Groups	0	6	0			
Total	0	8				

Appendix 3.4: ANOVA for Bacteriological Properties of the Water Samples from TWP-A, TWP-B and TWP-C Compared

Appendix 3.4.1: ANOVA for comparison of Total Coliforms of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	988.963	2	494.4815	0.399136	0.675271	3.402826
Error/Residuals	29733.11	24	1238.88			
Total	30722.07	26				

Appendix 3.4.2: ANOVA for comparison of Faecal Coliforms of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	180.2222	2	90.11111	3.390941	0.050465	3.402826
Error/Residuals	637.7778	24	26.57407			
Total	818	26				

Appendix 3.4.3: ANOVA for Comparison of E. coli of the Water Samples from TWP-A, TWP-B and TWP-C

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Manufacturers	26.74074	2	13.37037	3.479518	0.047107	3.402826
Error/Residuals	92.22222	24	3.842593			
Total	118.963	26				