UNIVERSITY OF EDUCATION, WINNEBA

QUALITY OF SACHET WATER VENDED AS DRINKING WATER IN WINNEBA

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DECLARATION

Student's Declaration

I, Ruby Kuntunuori Jia, declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and that it has not been submitted, either in part or whole, for another degree in this university or elsewhere.

Signature: ……………………………

Date: ……………………….…………

Supervisors' Declaration

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of thesis/dissertation/project as laid down by the University of Education, Winneba.

Dr. Guy Eshun (Supervisor)

Signature: ……………………………

Date: ……………………….…………

DEDICATION

To my lovely family.

ACKNOWLEDGEMENTS

To God be the glory, great things he has done. My warmest gratitude goes to all my lecturers, most especially my supervisor, Dr. Guy Eshun for his expertise and guidance throughout the stages of this study.

"Barka" to my lovely family and friends for their continuous support and great love.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The study sought to assess the quality of selected brands of sachet water vended in Winneba as drinking water. Specifically, it sought to assess the physicochemical properties (pH, colour, conductivity, turbidity, total hardness, total dissolved solids of sachet water), to determine the level of minerals in respect of calcium, magnesium, iron, chloride, sulphate and phosphate in the sachet water, and to evaluate the bacteriological quality (*Enterobacter,* Coliform, *E.coli, Salmonella enterica*) of the water as well as to evaluate the human health risk associated with the consumption of sachet water vended in Winneba. Eight sachet water samples collected from Winneba were used. Laboratory tests were carried out in triplicates. The results were compared with both World Health Organization (WHO) and Ghana Standards Authority (GSA) standards for thorough discussions**.** The results indicated that the sachet water samples demonstrated safe physicochemical properties, with pH, colour, and conductivity levels all meeting the WHO and GSA standards. The calcium, iron, chloride, sulphate, and phosphate levels in the sachet water samples demonstrated consistency across the brands. The study recommends that producers should implement continuous monitoring of physicochemical parameters, prioritize improving hygiene and disinfection protocols during the packaging, storage, and transportation of sachet water to prevent microbiological contamination.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Water is probably the most vital element among the natural resources and the most indispensable need for existence of all living things (Sohail et al., 2017). Undoubtedly, shortage of safe water leads to disease outbreak and economic loss, hence water is a necessity. In a nutshell without water life is impossible. Human life depends to a large extent, on water. It is used for an array of activities; chief among these being domestic such as for drinking, food preparation, bathing as well as for industrial purposes in pharmaceuticals among others. Since safe drinking water is essential to health, a community lacking good quality of this resource will be saddled with a lot of health problems which could otherwise be avoided (Amosah et al., 2023).

Water is one of the most abundant and essential commodities of man occupying about 70% of the earth's surface, yet a relatively high percentage of the world's population, most especially in developing countries live without access to safe water (Oludairo & Aiyedun, 2015). Globally, water is known to be a scarce resource and it has been estimated that 41% of the world's population live under water stress condition, while about 21% of the people live without access to potable water (Ngmekpele & Hawkins, 2015). However, access to clean water is worse in developing countries, where one-third of the population have no access to safe drinking water, resulting in the deaths of nearly 1.87 million children from diarrhoea annually.

Because water is an essential requirement of life for drinking, domestic, industrial and agricultural uses, its quality and quantity which vary over space and time are important components in the integral development of any area. Any change in the natural quality of water may disturb the equilibrium system and it would become unfit for designated uses. Over the past few decades, improvements have been made regarding the availability of clean drinking water. Between the year 2000 and 2017, the proportion of the world's population with access to drinking water increased from 81% to 89% (Pal et al., 2018). Despite this development, there are still significant differences in who has access to clean drinking water, depending on where they live and who they are globally. For instance, compared to 9% in Latin America and the Caribbean, an estimated 63% of the population in sub-Saharan Africa did not have access to drinking water services in 2017 (Li et al., 2019; Amosah et al., 2023).

The decreasing availability of water, both in quality and quantity, has been a major public health concern in Africa, particularly in Ghana. Access to clean and safe drinking water is a fundamental human right and a critical component of public health. However, in many developing regions, including Ghana, access to potable water remains a significant challenge (Amoah, 2016). In response to this issue, the consumption of sachet water has increased substantially over the past decade, especially in urban and peri-urban areas. There are still issues with maintaining the quality of drinking water despite government and private sector investments in water infrastructure in Ghana to increase access to safe water (Owusu, 2015; Amosah et al., 2023; Pal et al., 2018) sale and consumption of packaged water are growing increasingly in Ghana as in other low and middle-income countries of the world.

The evolution of water vending industry in Ghana points out interesting transformation from hawkers carrying water in containers on their heads and sold to consumers from plastic cups. Stoler et al. (2014) recall that the practice raised a lot of safety and health issues as different consumers shared the same cup. Then came water sold in hand-tied plastic bags, also raising several questions especially about the source of the water which was usually of unguaranteed quality and also hygienic practices especially in the handling. Currently, sachet water consists of 500 ml of plastic bags of water that are heat sealed and popularly termed as “pure water” due to its perceived safe and hygienic condition (Sohail et al., 2017). This is thought to be cheaper and more affordable than bottled water and also safer, more hygienic and better than hand filled, hand tied packaged polythene bag water initially popularly sold. Consequently, sachet water has gradually become the most consumed form of water for both the rich and poor (Rahman et al., 2019; Stoler et al., 2014).

Sachet water production is essential in Ghana, creating thousands of job opportunities and making a sizeable economic contribution. Sachet water manufacturing makes up almost 70% of all packaged water produced in Ghana (Amoah, 2016), with an estimated annual turnover of four hundred million Ghana cedis. With small-scale business owners operating in various regions, the industry has also been observed to support the informal sector. Additionally, the development of other allied businesses, like packaging and labeling, transportation and logistics, as well as distribution, has benefited from the production of sachet water, stimulating economic growth across the nation.

The proliferation of sachet water production resulting from high patronage, perhaps leads to substandard products on the market for want of profit (Stoler et al., 2014). Drinking water that is fit for human consumption is expected to meet national standards and that of the World Health Organization (WHO) standard, and be free from physical and chemical substances and micro-organisms in an amount that can be hazardous to health (Owusu, 2015). It is widely believed that no single method of purification can eliminate all contaminants from drinking water. However, water can and should be made safe for consumption within acceptable limits (Li et al., 2019; Sila, 2019).

Unfortunately, however, current trends in research (Olowe et al., 2016) suggest that sachet water could be a route of transmission of enteric pathogens which raises issues of the problem of its purity and health concern. The quality of sachet water is often questioned due to varying reports of contamination and inadequate regulatory oversight. Several studies (Sohail et al., 2017; Stoler et al., 2014) have highlighted concerns about the physicochemical and microbiological quality of sachet water. Typically, Stoler et al. (2014) found that some sachet water samples in Accra, Ghana, contained contaminants exceeding the acceptable limits set by the World Health Organization (WHO). This raises significant public health concerns, given the widespread consumption of sachet water across the country. Similar issues have been reported in other regions including Sunyani, indicating the need for comprehensive quality assessments (Ofosu et al., 2020; Sila, 2019).

Physicochemical characteristics such as pH, turbidity, total dissolved solids (TDS), and electrical conductivity are critical indicators of water quality. These parameters can affect the aesthetic qualities of water, such as taste and appearance, as well as its suitability for consumption. Studies have shown that deviations from the recommended physicochemical parameters can pose health risks. For instance, high turbidity can harbour micro-organisms, while inappropriate pH levels can affect the solubility and toxicity of chemical constituents in water (WHO, 2017).

Understanding and monitoring the quality of sachet water in Winneba is essential for ensuring its safety and acceptability, contributing to ensuring that the population has access to water that is safe, free from harmful contaminants, and acceptable for consumption. This directly addresses the goal of providing sustainable access to safe drinking water, a key target under Millennium Development Goals (MDG 7)

Microbial contamination of drinking water is a major concern, particularly in regions with inadequate sanitation and water treatment infrastructure. Pathogens such as *Escherichia coli* and coliform bacteria are commonly used indicators of faecal contamination in water. Previous research has identified the presence of these and other harmful micro-organisms in sachet water, posing serious health risks, including gastrointestinal diseases (Pal et al., 2018). The assessment of bacteriological quality in this study aims to determine the extent of microbial contamination in sachet water in Winneba and its implications for public health.

In addition to microbial contaminants, high concentration of anions (nitrates, chlorides) and cations (calcium, magnesium) in drinking water can significantly impact health. High levels of certain ions can lead to conditions such as methemoglobinemia (blue baby syndrome) or contribute to cardiovascular diseases (Sila, 2019). Furthermore, the total hardness of water, determined by the concentration of calcium and magnesium ions, can affect its taste and suitability for household use (WHO, 2017). This study analyzed these chemical constituents in sachet water to ensure the sachet water met standards.

1.2 Statement of the Problem

Access to safe and clean drinking water remains a critical challenge in many developing countries, including Ghana. Despite the increased consumption of sachet water in urban and peri-urban areas such as Winneba, there are growing concerns about its quality. Numerous studies have reported that sachet water may not always meet the required safety standards, posing significant health risks to consumers. For instance, Cheabu and Ephraim (2014) found that some sachet water samples at Obuasi contained contaminants that exceeded acceptable limits, highlighting the potential dangers of relying on these sources for drinking water. This problem is perhaps compounded by inadequate regulatory oversight and regular quality assessments, which are essential for ensuring the safety of sachet water.

The physicochemical characteristics of water such as pH, turbidity, total dissolved solids (TDS), and electrical conductivity, are vital indicators of its quality and suitability for consumption. Deviations from the recommended standards for these parameters can lead to adverse health effects and compromise the safety of drinking water. High turbidity, for example, can harbour harmful micro-organisms, while inappropriate pH can affect the solubility and toxicity of chemical constituents in water (World Health Organization [WHO], 2017). Despite the critical importance of these factors, the researcher observes paucity of current research data on the physicochemical quality of sachet water in Winneba, necessitating a thorough assessment to ensure public health protection.

Moreover, the bacteriological quality of sachet water is a major concern, as microbial contamination can lead to water-borne diseases, which are prevalent in areas with inadequate water treatment and sanitation infrastructure. Previous research has identified the presence of pathogens such as *Escherichia coli* and *Coliform bacteria* in sachet water, posing serious health risks, including gastrointestinal illnesses (Sila, 2019). Additionally, the concentration of anions, cations, alkalinity and total hardness in water can significantly impact health outcomes. High levels of certain ions including calcium and magnesium can contribute to health conditions such as cardiovascular diseases. Therefore, there is an urgent need to evaluate the overall quality of sachet water in Winneba to mitigate potential health risks and ensure the safety and acceptability of this widely consumed water source.

1.3 Purpose of the Study

The Purpose of this study was to assess the quality of sachet water vended as drinking water in Winneba.

1.4. Objectives

The objectives of the study are to:

1. assess the physicochemical properties (pH, colour, conductivity, turbidity, total hardness, total dissolved solids of sachet water vended in Winneba.
2. determine the level of minerals in respect of Calcium, Magnesium, Iron, Chloride, Sulphate and Phosphate in the sachet water.
3. evaluate the bacteriological quality (*Enterobacter, Coliform, E. coli, Salmonella enterica*) of sachet water vended in Winneba.
4. evaluate the human health risk associated with the quality of sachet water vended in Winneba.

1.5 Research Questions

1. What are the physicochemical properties (pH, colour, conductivity, turbidity, total hardness, and total dissolved solids) of sachet water vended in Winneba?
2. What are the concentrations of Calcium, Magnesium, Iron, Chloride, Sulphate, and Phosphate contained in sachet water vended in Winneba?

3. What is the bacteriological quality of sachet water vended in Winneba with regards to Enterobacter, Coliform, *E. coli, Salmonella enterica*?
4. What are the potential human health risks associated with the consumption of sachet water vended in Winneba?

1.6 Significance of the Study

It is widely admitted that the quality of drinking water is a fundamental determinant of public health, and that ensuring its safety is crucial. The significance of this study stems from the understanding that quality of sachet water in Winneba is essential to prevent potential health risks. The study hopes to provide comprehensive data on the physicochemical, minerals and bacteriological properties of sachet water, and their implications on human health, which can inform policy and regulatory improvements.

Again, Sachet water is widely consumed due to its affordability and convenience. A move to ensuring its quality, through research, can have significant economic and social benefits, reducing healthcare costs associated with water-borne illnesses and improving the overall quality of life for residents in Winneba and Ghana at large. By assessing and improving the quality of sachet water, this research contributes to providing safe drinking water for mankind, which is a critical component of sustainable development.

1.7 Delimitation of the Study

The study is delimited to the assessment of sachet water vended in Winneba with special focus on physicochemical properties including pH, colour, taste, turbidity, total hardness, total dissolved solids (TDS). An assessment was also made of the levels of Calcium, Magnesium, Iron, Sodium, Chloride, Sulphate and Phosphate in the sachet water. The study further evaluated bacteriological quality of sachet water, concentrating on *Enterobacter*, *E.coli*, and *Salmonella*. The assessment is limited to sachet water brands that are commonly vended in various locations across Winneba, excluding other forms of packaged water like bottled water. The assessment and evaluations of physicochemical properties, bacteriological quality and levels of mineral contamination were done to determine human health risk associated with the quality of sachet water.

1.8 Limitations of the Study

The cross-sectional and experimental design of this study limited the generalizability of the results to other seasons, regions, or production batches because sachet water quality may change over time (Sila, 2019) and distribution conditions (Rahman et al., 2019). The study also sampled sachet water brands within a specific geographic location (Winneba) and time period (September-December 2024). Although the purposive sample method is suitable for controlled laboratory examination, it may potentially create selection bias by leaving out less accessible brands that locals frequently use. Additionally, the study did not incorporate sophisticated molecular techniques for microbial identification, which could have resulted in an underestimation of pathogen diversity, and it relied on single-source laboratory testing, which may limit inter-laboratory comparability (APHA, 2017). Notwithstanding these limitations, the study offers a reliable baseline assessment of Winneba's sachet water quality in respect to national and international requirements.

1.9 Organization of the Study

The study has been organized under five chapters. Chapter One gives the introductory part covering the background to the study, the main and specific objectives, and the hypothesis. It further outlines the research questions which guide the attainment of the research objectives, the delimitation of the study as well as the significance of the study. Chapter Two reviews previous relevant literature to provide an in-depth knowledge of the area of study. Under this chapter, a review is made on some theories to underpin the current research and extends to various concepts and empirical studies of other authorities. Chapter Three discusses the methodological approach adopted for the study. It explains the research design, sample and sampling procedure as well as data collection procedure. The chapter further explains the method of data analysis a well as ethical considerations. The fourth chapter focuses on analysis and discussion of the results in relation to literature, and also in line with the study objectives. Chapter Five, summarizes the main findings of the study, presents conclusions and makes recommendations for stakeholders and suggestions for future study.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

Literature review is a foundational component of academic research writing, serving several key purposes that are integral to the development of a scholarly study (Pal et al., 2018). In essence, the literature review is a critical component of academic research that contextualizes the research, identifies gaps, develops a theoretical framework, and offers methodological insights. By synthesizing and critically analyzing existing literature, it sets the stage for the study, demonstrating its relevance and positioning it within the broader academic discourse (Owusu, 2015).

2.1 Theoretical Frameworks

For this research, assessing the physicochemical and bacteriological quality of sachet water in Winneba, two theoretical frameworks: Water Quality Index (WQI) framework and the Risk Assessment Framework have been chosen as theoretical underpinning to offer a unique perspective and to set principles that can guide the research methodology and analysis, ensuring comprehensive and reliable outcomes.

2.1.1 Water Quality Index (WQI) Framework

The Water Quality Index (WQI) is a tool used to aggregate various water quality parameters into a single, composite index that represents the overall quality of water. It involves the selection of specific parameters, their measurement, and the use of a formula to combine these measurements into an index score. Research (Li et al., 2019) has found WQI framework relevant as it provides a systematic approach to selecting and evaluating the critical physicochemical parameters of sachet water, such as pH, turbidity, total dissolved solids (TDS) and electrical conductivity. These parameters are essential indicators of water quality and suitability for consumption (Sila, 2019).

By using WQI, the study can simplify complex data into an easily understandable format for stakeholders, including policy makers, public health officials, and consumers. This helps in communicating the findings effectively and facilitating informed decision-making. In a supporting submission, Li et al. (2019) and Amosah et al., 2023 share the view that WQI allows for comparison of water quality across different brands of sachet water and with established standards. This comparative analysis is crucial for identifying brands that meet safety standards and those that require regulatory attention.

2.1.2 Risk Assessment Framework

The Risk Assessment Framework involves identifying potential hazards, evaluating the exposure and potential health effects, and estimating the risk associated with these hazards. It typically includes hazard identification, dose-response assessment, exposure assessment, and risk characterization. This framework is relevant for the study's objective of evaluating the human health risks associated with the quality of sachet water. It helps in systematically assessing the likelihood and severity of adverse health effects due to contaminants found in the water (Ntengwe et al., 2016).

By integrating data on physicochemical and bacteriological quality, the Risk Assessment Framework (RAF) enables a comprehensive analysis of how different contaminants can impact health. This approach helps in identifying priority areas for intervention and risk mitigation. This framework, according to Pal et al. (2018), provides a scientific basis for setting acceptable limits for various contaminants and for designing targeted interventions to protect public health.

2.2 Conceptual Framework

Conceptually, the study assesses the physicochemical and bacteriological quality of sachet water in Winneba to determine its compliance with WHO and Ghana Standards Authority (GSA) guidelines for drinking water. A conceptual framework, according to Li et al. (2019), is essential in research as it provides a structured approach to identifying relationships between variables, it helps researchers clarify key concepts, define research boundaries, and establish a logical flow, thereby ensuring a coherent investigation. This framework examines the interrelationships between water source and processing, measured water quality parameters, and public health implications. The study is therefore conceptualized as diagrammatically presented in Figure 1:

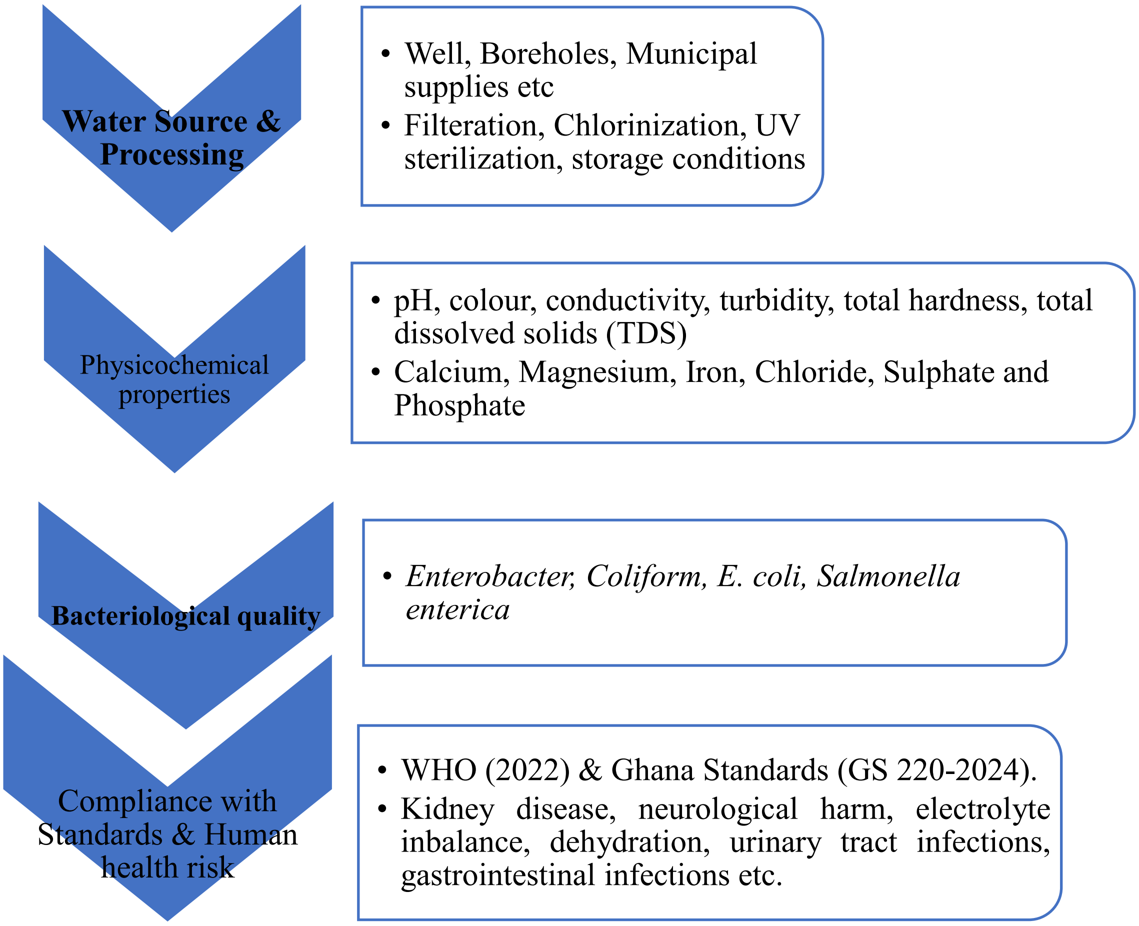

Figure 1: Conceptual Framework Diagram

Studies (González et al., 2021; Osei et al., 2022; Onuorah et al., 2017) hold that the quality of sachet water is influenced by the source of raw water such as boreholes, municipal supplies, or wells, as well as the treatment and packaging processes**.** The effectiveness of these treatments, such as filtration, chlorination, Ultraviolet (UV) sterilization, and storage conditions plays a critical role in determining the final quality of the water consumed by the public. Poor handling or inadequate treatment can introduce physical, chemical, and microbial contaminants (Asare et al., 2020; Onuorah et al., 2017).

As part of the assessment of water quality, physicochemical parameters are analyzed, which invariably include the pH to indicate the water's acidity or alkalinity, total dissolved solids (TDS) and electrical conductivity reflecting the presence of dissolved ions (Asare et al., 2020). Also, total hardness is analyzed to determine the concentration of calcium and magnesium, turbidity is measured to access water clarity and alkalinity is evaluated to indicate the water's buffering capacity. Other minerals relevant for analysis include sulphates, nitrates, and phosphates, which, in excess, can indicate contamination. Iron and other heavy metals are also accessed, elevated levels can pose significant health risks and therefore requires careful consideration in water quality evaluation (Nyarko et al., 2023).

Microbial contamination is a significant public health concern. The current study measures total coliforms, as general indicators of microbial contamination, faecal coliforms (*E. coli*), which confirm faecal contamination and potential pathogenic risk, and other pathogenic indicators (*Enterobacter, Total Coliform, Salmonella enterica*), to evaluate the safety of sachet water for human consumption. To determine compliance with water quality standards and health implications, results from the study are compared with WHO and Ghana Standards Authority (GSA) guidelines. If physicochemical or bacteriological parameters exceed permissible limits, the water may pose potential health risks such as gastrointestinal diseases, heavy metal toxicity, or long-term health issues (Sunday et al., 2021). The study provides insights into the safety of sachet water consumption and informs recommendations for improving water quality control measures.

2.3 Quality of Drinking Water

Most literature describes water quality as the chemical, physical or biological characteristics by which the user evaluates the acceptability of water (Guissouma et al., 2017). One can therefore assess water quality by examining its physiochemical parameters, total organic parameters, radionuclides, heavy metals and bacteriological parameters. Similarly, Rahman et al. (2019) posit that water quality can be assessed generally by examining the physicochemical properties, and the organic and inorganic compounds that are dissolved or suspended in it.

Moreover, Cheabu and Ephraim (2014) assert that water quality is most often defined by its physicochemical and bacteriological standards; therefore, good quality sachet water must comply with the guideline limits set by both international and local water regulatory bodies. Addo et al. (2014) forewarn that if on the other hand, 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.

One of the major and critical problems in most developing countries, including Ghana, today is the provision of an adequate and safe drinking water to its populace (Ngmekpele & Hawkins, 2015). Drinking water that is safe and aesthetically acceptable is a matter of high priority to the World Health Organization (WHO) and other regulatory bodies such as Food and Drugs Authority (FDA) and Ghana Water Company in Ghana. Furthermore, drinking water that is fit for human consumption is expected to meet set standards of the World Health Organization (WHO) and be free from physical and chemical substances and microorganisms in an amount that can be hazardous to health.

2.4 Global need for Quality Water

A commonly accepted definition of quality water in research and academia is that it free from pathogenic organisms, turbidity, odour, taste, toxic substances, and colour while containing acceptable levels of minerals and organic matter (Guissouma, et al., 2017). Premised from the estimation of population growth rate and perhaps the reckless increasing human activities such as mining and climate change, the fourth assessment report of the Intergovernmental Panel on Climate (IPCC) stated in the year 2012 that twelve countries would be limited to 1,000 to 1,700 m^3 of potable water per person in a year (Rahman et al., 2019). According to the report, the number of people in the countries at risk could be 460 million in the next decade, which is mainly in West Africa.

Fundamentally, human beings have the right to supply of clean water. Regardless, WHO still records that there are over 1 billion people in this world who still cannot access quality water supply for domestic purposes. This gives a data of 6% of the world's population lacking access to clean water in the urban areas, with 29% lacking access in the rural areas (Cheabu & Ephraim, 2014). This challenge is experienced both in remote and rural areas in developed countries as well as in municipalities of developing nations. Research has recounted that inadequate quality water supply leads to a large and disastrous event of great significance causing diarrhoea disease to kill about 2.2 million people in a year, which relates to one person dyeing in every 15 seconds (Addo et al., 2014).

Recounting the importance of quality drinking water in a related discourse, Thliza et al. (2018) emphasized that water is one of the indispensable resources for mankind. Tracing back to the year 1978, provision of adequate supply of quality drinking water was one of the eight components of primary health care identified by the International Conference on Primary Health care (Ngmekpele & Hawkins, 2015). Changes in physical characteristics such as transparency, temperature, suspended solids and other chemical characteristics of water such as dissolved oxygen, chemical oxygen demand, nitrate and phosphate provide valuable information on the quality of the water.

Guissouma et al. (2017) contributed to the narratives of Ngmekpele and Hawkins (2015) on the importance of water and submitted that, quality water plays an important role in the digestion of food in the body, transporting in the blood stream the required nutrients needed by the body for growth and repair of muscle tissue. Access to drinking water is a fundamental need and a human right which is vital for the dignity and health of all people.

Placing high premium on the importance of water, the Millennium Development Goal (MDG) target -7 called for reducing by 50% the proportion of people without sustainable access to quality/safe drinking water by the year 2015 (Abdullahi & Namadina, 2019). The World Health Organization (WHO) therefore recommended for nations the need for comprehensive strategies to tackle both the quantity (access, scarcity) and quality (safety) dimensions for provision of quality drinking water. It is estimated that about 884 million people in the world today still do not get their drinking water from improved sources, with majority of them being in developing regions (Li et al., 2019).

Sub-Saharan Africa accounts for over a third of that number and is lagging behind in the progress towards the Millennium Development Goal target-7 with only 60% of the population using improved sources of drinking water despite an increase of 11% points since 1990 (Olowe et al., 2016; Li et al., 2019). In Ghana for instance, Awuah et al. 2014) estimated that approximately 10.3 million people (51%) have access to improved water supplies and for the 8.4 million residents in the country's urban areas this increases slightly to 61% with two thirds of these (40%) covered by the Ghana Water Company Limited (GWCL) networks.

It must however be emphasized that access to adequate quality water seems to have improved greatly in some regions and countries especially in the developed world, but for poor and developing nations, this is still a major issue as contaminated water kills more people than cancer, AIDS, wars, terrorism or accidents (Cheabu & Ephraim, 2014). The World Academy of Sciences (TWAS) remarked in the year 2002 how pertinent it is to keep water meant for human consumption free of disease-causing germs and toxic chemicals that pose a threat to public health (Dzodzomenyo et al., 2018).

2.5 Sachet Water Production in Ghana

Drinking water vending in Ghana started as venders carried water in pots and buckets and served consumers in cups. During the 1970s and 1980s, it was very common to buy a cup of drinking water on the streets of Ghana. Awuah et al. (2014) recall that concerns arose from the unhygienic nature of serving numerous consumers drinking from the same cup. To resolve this concern, vendors started simple sachet water production and sale in hand-filled and hand-tied plastics bags which were popularly called "Ice Water" (Awuah et al., 2014). They were known as ice water because most of the vendors added blocks of ice to the sachet water, which were contained in ice boxes to cool the water.

These early stages of sachet water production procedure also met some criticisms from the public. Ngmekpele and Hawkins (2015) narrate that producers used to blow air from their mouths to open polythene bags to allow filling in water, coupled with the usually untidy cups and buckets with which they fetch water from basins. Subsequently, consumers attributed these forms of drinking water to sanitation shortcomings and possibly contributing to outbreak of diarrhoea (Ofosu et al., 2020). The introduction of sachet water in the country was to provide safe, clean and affordable instant drinking water to the people, in general, and to check the magnitude of water-related diseases in the nation.

During the late 1990s, new Chinese machinery that heat-sealed water in a plastic sleeve effectively created the modern sachet that is currently sold on the streets of Ghana and other several West African nations. Filtration and chemical treatment processes were eventually built into some of the high-end machines as well. There are both small and large-scale industries that pack and machine-seal sachet water in Ghana. These packed and machine-sealed sachet water is commonly known by many of the locals as "Pure Water" (Ofosu et al., 2020).

Amoah (2016) describes a typical production process that, a water pump draws directly from a piped connection of municipally-treated water or from a storage tank or borehole. Sachet water produced in small-scale industries are mainly treated by aeration, double or single filtration using porcelain molecular candle filters or membrane filters and in rare instances, disinfection is applied. Typical sachet production process is as shown in Figure 2.

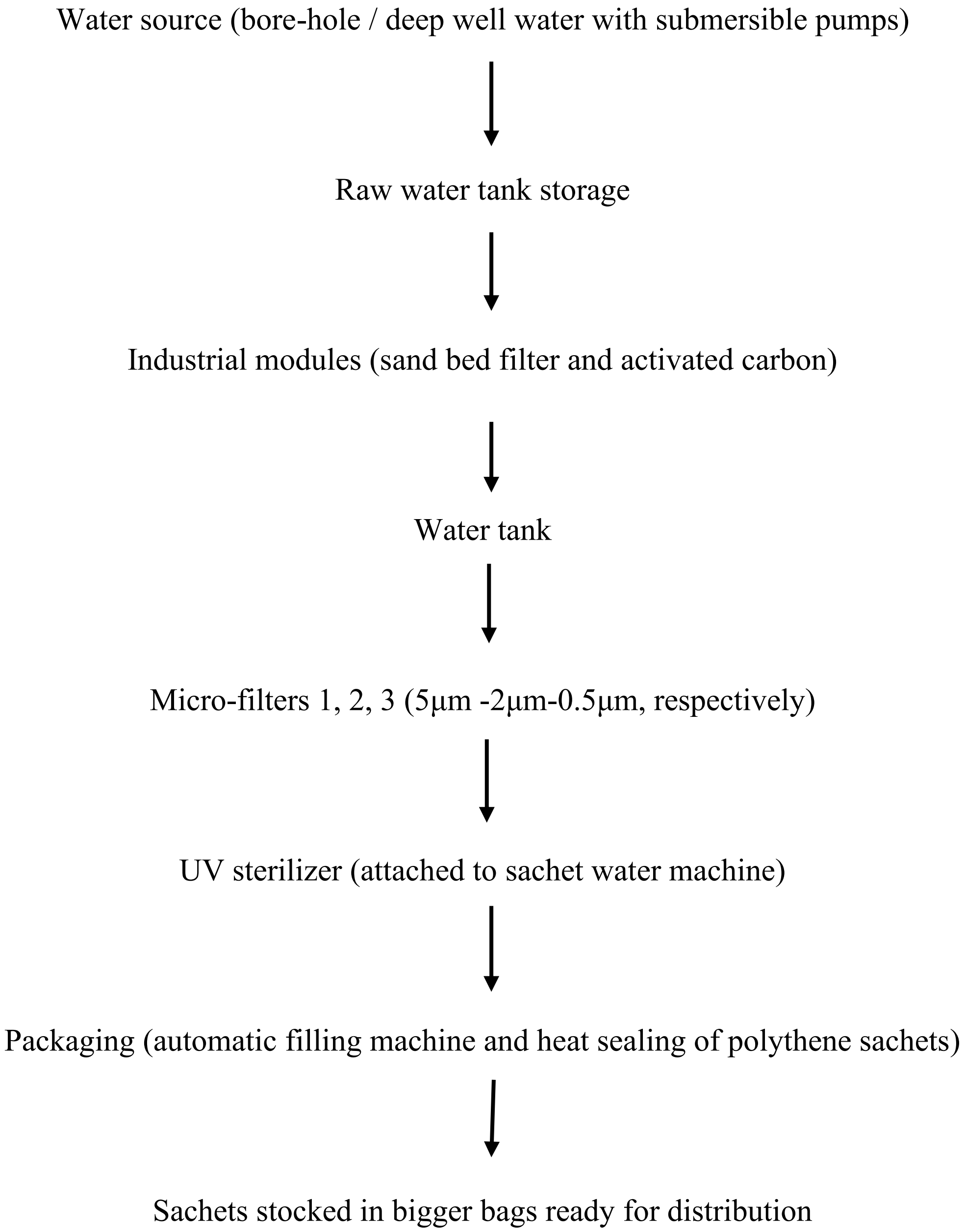

Figure 2: Process for the production of sachet water

Sachet water production is regularized in Ghana by the Food and Drugs Authority and the Ghana Water Company Limited standards as contained in Ghana Standards Authority (GSA) guidelines adapted from the World Health Organization (WHO), 1993 standards for drinking Water Quality. As indicated in Amoah (2016), the 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 revised in 2024 (Table 1). Dzodzomenyo et al. (2018) explain the word "standards" as referring to legally enforceable threshold values for the water parameters analysed, while "guidelines" refer to threshold values and do not have any regulatory status.

Table 1: Guideline values with GSA and WHO standards for drinking water quality

Parameter	Unit	WHO guideline values	GWCL Standards
TDS	mg/L	0-1000	0-500
Colour (apparent)	Hz	0-15	0-5
Turbidity	NTU	0-5	0-5
Conductivity	µS/cm	-	1000
Total Alkalinity	Mg/L		
Total Hardness	m/L	0-500	0-500
Mag. Hardness	mg/L		150
Phosphate (PO_4^{3-})	m/L		
Silica (SiO_2)	mg/L		
Sulphate (SO_4^{2-})	m/L	0-400	0-250
Calcium	m/L	0-200	200
Nitrate (NO_3^{2-})	mg/L	0-10	0-50
Chloride	m/L	0-250	0-250
Magnesium	m/L	0-150	150
Potassium	mg/L	0-30	
Sodium	mg/L	0-200	
Bicarbonate	mg/L		
Ph	pH	6.5-8.5	6.5-8.5
Fluoride	mg/L	0-1.5	0-1.5
Total Coliform	1/100Ml	0	0
Faecal Coliform	1/100Ml	0	0

The level of treatment generally depends on the source of water. However, sometimes tap water is used without additional treatment and is sold in markets without clearance from the Food and Drugs Authority of Ghana or other bodies concerned with water quality.

Ofosu et al. (2020) explain that production, sale and consumption of sachet drinking water continue to grow rapidly in Ghana because most urban and rural communities do not have adequate reliable and safe water. Sachet water is commercially treated and packaged water which is distributed for sale, usually in 0.5 Litre (L), intended for human consumption.

Ngmekpele and Hawkins (2015) opined that sachet water was brought into the market as a more affordable means of accessing drinking water as an improvement over the former forms of drinking water packaged for sale in hand-filled and hand-tied polythene bags. Quite a while after the introduction of sachet water, there have been enormous increase in the utilization of sachet water, partly because of increasing concerns about the safety of piped water supply, and an increased influx of individuals into the significant shopping areas with a prerequisite for good drinking water (Ofosu et al., 2020).

2.6 Physicochemical Characteristics of Drinking Water

The physicochemical characteristics of drinking water are crucial indic;’l,ators of its quality and suitability for human consumption. The physical properties of drinking water are crucial indicators of its quality, impacting both aesthetic values and potential health outcomes. Key physical parameters include turbidity, colour, taste, odour, temperature, and total dissolved solids (TDS) (Dzodzomenyo et al., 2018). Physicochemical parameters such as pH, turbidity, total dissolved solids (TDS), and electrical conductivity provide essential information about water’s aesthetic qualities and potential health risks (Olowe et al., 2016). According to the World Health Organization (WHO), these parameters must meet specific guidelines to ensure water safety (WHO, 2017). In Ghana, sachet water has become a popular alternative to tap and bottled water, particularly in urban and peri-urban areas where access to safe drinking water is limited. The growing reliance on sachet water necessitates rigorous quality assessments to safeguard public health.

Previous studies have highlighted concerns about the physicochemical quality of sachet water in various regions. For instance, research conducted by Stoler (2014) in Accra found that several sachet water brands did not meet the WHO standards for pH, turbidity, and TDS. These deviations pose significant health risks, as high turbidity can indicate the presence of pathogens, and inappropriate pH levels can affect the solubility and toxicity of chemical contaminants. Additionally, high levels of TDS can result in an unpleasant taste and potential long-term health effects, including kidney stones and cardiovascular issues (WHO, 2017).

2.6.1 Turbidity

Turbidity, a measure of water’s cloudiness due to suspended particles, can significantly influence the water’s appearance and palatability. Turbidity, a key physical property of water, refers to the degree of cloudiness caused by the presence of suspended particles such as clay, silt, organic matter, and microorganisms. Dzodzomenyo et al. (2018) report that these particles affect the aesthetic quality of the water, making it less appealing for consumption, and as well serve as determining factor to the safety of water. High turbidity levels can obscure the water’s clarity, leading to a perception of poor quality, which can affect consumer confidence and willingness to drink the water. More importantly, turbidity can significantly influence the effectiveness of water treatment processes, particularly disinfection. Elevated turbidity levels shield harmful microorganisms, such as bacteria, viruses, and protozoa, from being fully exposed to disinfectants like chlorine (Addo et al., 2014).

When pathogens are protected by these particles, the risk of waterborne diseases increases, as the disinfection process becomes less effective. This can lead to the survival and subsequent ingestion of harmful microorganisms, potentially causing gastrointestinal infections, diarrhoea, and other health problems (WHO, 2017). Giving further elaborations, Thliza et al. (2018) indicated that protozoan parasite (*Cryptosporidium*) is known to be resistant to chlorine disinfection, and its presence in turbid water can lead to outbreaks of cryptosporidiosis, a severe diarrhoeal disease. Moreover, the presence of organic matter in turbid water can react with disinfectants to form harmful disinfection by-products (DBPs), which have been linked to long-term health effects such as cancer. Therefore, controlling turbidity is crucial not only for improving the aesthetic quality and palatability of drinking water but also for ensuring that disinfection processes are effective, thereby reducing the risk of waterborne diseases.

2.6.2 Colour

Similarly, the colour of water, while not always directly harmful to human health, serves as a critical indicator of potential contamination. Abdullahi et al. (2019) opine that discoloration is often a result of the presence of organic materials such as decomposing plant matter, or inorganic contaminants like iron and manganese. These substances can enter the water supply through natural processes or as a result of pollution from agricultural runoff, industrial discharges, or aging infrastructure (Addo et al., 2014). While the mere presence of colour does not necessarily indicate that the water is unsafe to drink, it often signals that the water has not been adequately treated or that there is a high level of certain compounds. Over time, exposure to these contaminants, especially metals like iron and manganese, can pose health risks. For instance, prolonged consumption of water with elevated iron levels may lead to conditions such as hemochromatosis, a disorder that causes iron accumulation in the body, potentially damaging organs (Dzodzomenyo et al., 2018).

Furthermore, the colour of water can also indicate the presence of other harmful substances that may not be immediately visible or detectable without specialized testing. Guissouma et al. (2017) add that coloured water may contain dissolved organic carbon (DOC), which, when reacting with disinfectants like chlorine, can form disinfection by-products (DBPs) such as trihalomethanes (THMs). Studies have shown that these by-products are associated with an increased risk of cancer and adverse reproductive outcomes when consumed over long periods (Thliza et al., 2018). Therefore, while colour itself might not be directly harmful, it serves as a warning sign that the water may contain various contaminants, necessitating further investigation and treatment to ensure its safety for consumption. Ignoring such indicators can lead to the gradual buildup of harmful substances in the body (Stoler, 2014), emphasizing the importance of maintaining strict water quality monitoring and management practices.

2.6.3 Total dissolved solids (TDS)

Abdullahi et al. (2019) indicated that total dissolved solids (TDS), comprising inorganic salts and small amounts of organic matter, is another physical property with direct implications for health. Augustine et al. (2019) explain further that total dissolved solids (TDS) refer to the combined content of all inorganic salts and a small amount of organic matter dissolved in water. The primary constituents of TDS include calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates among others. Research (Oluwabunmi et al., 2018) has espoused that concentration of these dissolved substances in water is a critical physical property that can influence both the aesthetic qualities and health implications of the water.

As Oluwabunmi et al. (2018) put it, TDS levels in drinking water can affect its taste, with very low levels often leading to water that is tasteless, while higher levels can impart a salty, bitter, or metallic taste. Additionally, water with an unpleasant taste or odour may indicate contamination by organic or inorganic chemicals, which, although not always harmful in small quantities, can become a health hazard with prolonged exposure (Amosah, et al., 2023). Such sensory qualities are critical as they directly affect consumer perception and acceptance, potentially leading to the consumption of alternative, untreated water sources that may be unsafe. Beyond taste, TDS is a significant indicator of the overall quality of water, as it can provide insights into the presence of potentially harmful contaminants and the general suitability of the water for consumption (Abdullahi et al., 2019; Thliza et al., 2018).

Owusu (2015) on a similar study of the quality of sachet water sold in Techiman Municipality of Ghana, reported high turbidity levels in some samples, indicating poor filtration processes during production. Furthermore, the study found that TDS levels in certain sachet water brands exceeded WHO guidelines, raising concerns about the potential long-term health effects on consumers. These findings underscore the importance of continuous assessment and adherence to water quality standards to protect public health.

Augustine et al. (2019) reiterate that while low TDS levels are generally safe, high TDS concentrations in drinking water can result in adverse health effects. From the health perspective, the TDS level in drinking water is directly linked to potential health outcomes. Excessively high levels of TDS can pose health risks, particularly when the dissolved solids include harmful substances like heavy metals or nitrates. Studies have reported that prolonged consumption of water with high TDS can lead to gastrointestinal irritation and increase the risk of developing kidney stones due to the accumulation of minerals like calcium and magnesium (Amosah et al., 2023).

Nonetheless, extremely low TDS levels, often found in demineralized water, may lack essential minerals that are beneficial to health, potentially leading to deficiencies if consumed as the primary water source over time (WHO, 2017). Therefore, maintaining TDS within an optimal range is crucial for ensuring that drinking water is not only palatable but also safe and beneficial for long-term health. In regions like Winneba, where sachet water is a primary drinking source, consistent monitoring of TDS levels is necessary to ensure that the water remains within safe consumption limits.

2.6.4 The pH level

The pH level of water is a critical parameter influencing both its aesthetic quality and its interaction with other chemical constituents. WHO recommends a pH range of 6.5 to 8.5 for safe drinking water (Pal et al., 2018). Deviations from this range can lead to corrosion of pipes and increased solubility of toxic metals such as lead and copper, which pose severe health risks. Thliza et al. (2018) found that pH levels of sachet water brands in Ho, Ghana, varied widely with some samples falling outside the recommended range. This highlights the need for regular monitoring and stringent quality control measures to ensure the safety of sachet water.

2.6.5 Calcium and Magnesium

The study of the chemical components of the physicochemical properties of water cannot be underrated for its relatedness to water quality and suitability for consumption. These properties include the presence and concentration of essential minerals, trace elements, and potential contaminants such as heavy metals, nitrates, and fluoride (Augustine et al., 2019). Chemical properties significantly influence the potability of water, with both deficient and excessive levels of certain chemicals posing health risks. While minerals like calcium and magnesium are essential for human health, contributing to bone strength and cardiovascular function, Nathaniel et al. (2023) confirm that their excessive presence can lead to conditions such as kidney stones and hypertension. Similarly, a deficiency in these essential minerals, often found in distilled sachet water, may lead to negative health outcomes, including mineral deficiencies (Oluwabunmi et al., 2018).

Nathaniel et al. (2023) share scientific knowledge that calcium and magnesium are essential minerals commonly found in drinking water, including sachet water, and are vital for various physiological functions. It is known that calcium plays a crucial role in bone and teeth formation, muscle function, and nerve transmission. Magnesium, on the other hand, is involved in over 300 biochemical reactions in the body, including energy production, muscle and nerve function, and blood glucose control (Nathaniel et al., 2023; Oluwabunmi et al., 2018). However, Rahman et al. (2019) concords with Oluwabunmi et al. (2018) and advise that concentrations of these minerals in drinking water need to be carefully regulated as excessive calcium and magnesium contribute to water hardness, which, while not harmful to health, can lead to the scaling of pipes and appliances. In contrast, insufficient levels of these minerals in sachet water could potentially contribute to deficiencies, particularly in populations relying on this water as their primary source of hydration (Abdullahi et al., 2019).

2.6.6 Iron

In a contributory remark to the discourse of minerals in drinking water, Aji et al. (2017) suggest that iron is another essential mineral that is frequently found in sachet water, especially in areas with high iron content in the soil. While iron is necessary for haemoglobin formation and oxygen transport in the blood, its presence in drinking water should be minimal due to its potential to impart a metallic taste and cause staining of laundry and plumbing fixtures. In essence, high levels of iron in sachet water can also lead to the growth of iron bacteria, which can further deteriorate water quality and cause unpleasant odours. Studies (Amosah et al., 2023) have therefore recommended that long-term consumption of water with high iron levels, although rare, may contribute to conditions such as hemochromatosis, where excess iron accumulates in the body and can damage organs.

2.6.7 Chloride

It is common laboratory evidence that chloride is mostly found together in drinking water as a result of natural processes or human activities such as the use of salt. Prior studies (Amosah et al., 2023; Abdullahi et al. 2019) have confirmed that chloride, while generally harmless at low levels, can affect the taste of water and may indicate the presence of other contaminants such as industrial pollutants or sewage (Oluwabunmi et al., 2018).

2.6.8 Sulphates and Phosphates

Commonly found minerals in water also include sulphate and phosphate, occurring naturally from mineral dissolution. While sulphate at moderate levels has a laxative effect, especially in individuals not accustomed to it, research report that high concentrations can lead to dehydration and gastrointestinal discomfort (Abdullahi et al., 2019). Phosphate, though typically present in low concentrations in drinking water, is essential for energy production and bone health. However, excessive phosphate levels, often from agricultural runoff, can cause eutrophication in water bodies, indirectly affecting the quality of the water used for sachet packaging (Nathaniel et al., 2023).

Following research reports and empirical evidence regarding the contributions of these chemical constituents of sachet water vis-avis their health implications on human lives, monitoring and regulating the concentrations of these chemical constituents in sachet water are crucial. This is to ensure the safety and health benefits of water consumed by the public. More importantly, scientific research into the levels of concentration of these chemicals to complements wholistic efforts towards regulating the quality of water in general and sachet water for human consumption is pertinent. While these water constituents are vital for health (Pal et al., 2018), their balance in drinking sachet water must be maintained to avoid adverse health effects and to ensure that the water remains both palatable and safe for long-term consumption (Oluwabunmi et al., 2018).

2.6.9 Total Alkalinity

Alkalinity is a total measure of the substances in water which have acid-neutralizing ability and buffer its pH. Studies (Abdullahi et al., 2019; Onesmus et al., 2019) have consistently affirmed that alkalinity is necessary for the survival of life because it buffers against pH changes and makes water less vulnerable to high acid content. Yusuf et al. (2015) opine that 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 alkalinity and, consequently, good buffering capacities. Drinking water of high alkalinity is often known to have uncomfortable taste (Nathaniel et al., 2023). Alkalinity is expressed in mg/L and there are no standards and guideline values proposed by the WHO and GWCL (Addo et al., 2014).

2.6.10 Total Hardness

Hardness of water is essential for strong teeth and bones, prevention of heart diseases, normal vascular activities and synthesis of protein. Calcium and magnesium dissolved in water are the two most common minerals that make water "hard", along with contributions from various other metals. Water is an excellent solvent and readily dissolves minerals it comes into contact with. As water moves through soil and rocks it dissolves very small amounts of minerals and holds them in solution (Oluwabunmi et al., 2018).

2.6.11 Electrical Conductivity

This attribute of conductivity of water is the ability of water to conduct electricity. Water conducts electricity because it contains dissolved solid that carry electrical charges (Peter et al., 2019). The presence of these dissolved solids including sodium, magnesium, and calcium are indicative of 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 content, and can be affected by many factors including diluting mineral concentration, temperature and addition of salt to drinking water (Abdullahi et al., 2020).

Nations have set standards regarding the ideal water conductivity level for drinking water, such as typically recommended range of 30 to 1500 µS/cm for drinking water by the California State Water Resources Control Board (SWRCB) in USA.

2.7 Bacteriological Quality of Sachet Water

Onuorah et al. (2017) note that the growing populations in most developing countries are occurring in urban areas, creating opportunities to expand water supply infrastructure and improve water supplies. Water is also a major medium contributing to illness and infant mortality in many developing countries, and even poses risk in many technologically advanced nations. Although water-related diseases have been largely eliminated in the developed countries, Onuorah et al. (2017) express that they remain a major concern in most of the developing nations. The high prevalence of diarrhoea among children and infants can be traced to the use of unsafe water, mainly associated with bacteriological quality of drinking water.

The bacteriological quality of sachet water is a critical concern due to its direct implications for public health. Bacteria can be naturally present in the environment including water bodies and coliforms are among the possibly harmful bacteria that may be present in water. Packaged water, no matter their sources, are susceptible to microbial, toxic organic and inorganic contamination (Onuorah et al., 2017; Oluwabunmi et al., 2018).

The presence of coliforms in potable water is used as indicator of water contamination (Oluwabunmi et al., 2018). Coliform bacteria describe a group of enteric bacteria that include *E. coli*, *Klebsiella* and *Enterobacter* species among others. They are rod-shaped, gram-negative organisms which ferment lactose with the production of acid and gas when incubated at 37ºC for 48 hours. They are broad class bacteria that live in the digestive tract of humans and animals (Aji et al., 2017). Although coliforms are generally not harmful, they indicate the presence of pathogenic bacteria, viruses and protozoa (Abdullahi et al., 2020).

Bacterial contamination, particularly from faecal and non-faecal sources, can result in water-borne diseases and pose significant health risks to consumers. Faecal coliforms are mostly used to indicate the faecal contamination of water samples, and they mostly determine the presence of *E. coli* and certain species of *Enterobacter aerogenes* which should be absent in 100 ml of drinking water, as recommended by Ghana Standards Authority (GSA) set standards (Abdullahi et al., 2020).

Coliforms occur naturally in soil and in the gut of humans and animals. Thus, their presence in water may indicate contamination. *E. coli* and certain species of *Enterobacter aerogenes* are present only in the gut of humans and animals. Their presence, according to Onuorah et al. (2017), indicates definite faecal pollution. The presence of coliform bacteria in drinking water may be as a result of surface water infiltration or seepage from a septic system (Abdullahi et al., 2020). In Pal et al.'s (2018) study for instance, the assessment of bacteriological quality of sachet water found a considerable proportion of sachet water samples were contaminated with coliform bacteria, indicating faecal and non-faecal contamination and potential health hazards.

Total coliform is a term used to refer to a group of bacteria that are commonly found in the environment, in soil or vegetation and as well constitutes the normal flora in mammals including humans. These bacteria mostly do not cause any disease, but their presence in drinking water gives an indication that the water supply may be vulnerable to contamination from more harmful bacteria and other microorganisms (Onuorah et al., 2017).

Studies (Onuorah et al., 2017; Oluwabunmi et al., 2018) indicate that *E. coli* is a member of the total coliform group of bacteria that is found only in the intestines of mammals, including humans. Therefore, the presence of *E. coli* in water indicates recent faecal contamination which may mean the possible presence of disease-causing pathogens, such as bacteria, viruses and parasites. Due to this, total coliforms and *E. coli* are used as indicators to measure the degree of pollution and sanitary quality of water for purposes of drinking (Aji et al., 2017). This is mostly the case because testing for all known pathogens is a complicated and expensive process.

The WHO Guideline and GSA Standard values set for total coliform is zero. This is because there have been water borne diseases outbreaks in which researchers have found very low levels of coliform, an indication that any levels of indicator organisms have health risk. Several studies, including Amoah (2016) and Oludairo and Aiyedun (2015), have investigated the microbiological quality of sachet water in various regions, shedding light on the prevalence of pathogens and the effectiveness of water treatment processes. Typically, in Sila (2019) the microbiological quality of packaged water was evaluated and reported the presence of *Escherichia coli* in some samples, highlighting serious health implications for consumers. These findings underscore the need for stringent quality control measures to ensure the safety of sachet water.

Other researches in Nigeria (Onuorah et al., 2017) also investigated the microbial quality of sachet water sold in Awka and found high levels of microbial contamination, including the presence of pathogens such as *Salmonella* and *Shigella*. This study highlights the widespread nature of the problem and the need for comprehensive interventions to address microbial contamination in sachet water. Furthermore, a study by Sohail et al. (2017) in Pakistan revealed similar findings, with sachet water samples contaminated with coliform bacteria and faecal indicators, indicating poor water quality and potential health risks for consumers.

2.8 Mineral content and Total Hardness of Sachet Water

The study of total hardness is an important determinant of the suitability of water for drinking purposes. Several studies have investigated this parameter in sachet water to assess its overall quality and potential health implications. Research in Zambia (Ntengwe et al., 2016) evaluated the chemical composition of sachet water sold in Lusaka. The study found varying levels of anions such as chloride, sulphate, and nitrate, as well as cations like calcium, magnesium, and sodium in the samples. These findings highlight the diverse mineral content of sachet water and the need for regular monitoring to ensure compliance with quality standards.

Similarly, Thliza et al. (2018) in Nigeria assessed the physicochemical properties of sachet water samples from different brands. The researchers reported alkalinity levels within acceptable limits but observed variations in total hardness, with some samples exceeding recommended thresholds. This variability underscores the importance of consistent quality control measures to safeguard consumer health. In addition to studies in Africa, research conducted in other regions has also examined the chemical composition of sachet water. Rahman et al. (2019) investigated the physicochemical properties of sachet water sold in Bangladesh. The study revealed high levels of total dissolved solids (TDS) in some samples, indicating potential contamination or inadequate treatment processes. These findings underscore the need for improved water treatment and quality assurance measures to ensure the safety of sachet water for consumption.

2.9 Water Quality and associated Human Health Risks

The drinking of packaged water has since become full-fledged in recent times, most especially in high-income countries and recently in middle and even low-income countries of the world. Packaged water is typically a drinking water that is packed in a wide range of receptacles; plastic, glass bottles, sachets or bags. It usually comes in many sizes and sold in shops, vended on the street or delivered to homes Falnyi et al. (2022) further note that some packaged sachet water producers willingly comply with recommended quality, safety and hygiene standards, others either lack the capacity or deliberately produce substandard water fully aware that they are unlikely to face consequences. However, there is serious concern amongst governments and international organizations in that unregulated packaged sachet water may constitute public health concern.

The increasing demand for sachet water as a result of non-availability of reliable safe drinking water has been reiterated in most recent researches including Abideen et al. (2020). This creates the impression that most sachet water offers a healthy, safer and water with better and good quality. Despite general acceptability of packaged sachet water, some researches also show that there is a challenge associated with its quality as a result of isolation of some microbes and non-compliance with expected parameters.

The quality of drinking water is an influential environmental determinant of health, which is determined considering three major categories involving physical, chemical, and microbiological properties (Abideen et al., 2020). Assessing the human health risks associated with the quality of water is paramount to ensuring public health and safety. Contaminated water can harbour pathogens, chemical pollutants, and other hazardous substances that pose significant health risks to consumers. Waterborne disease outbreak is said to happen if two or more persons experience a similar illness after consumption or use of water intended for drinking, and epidemiologic evidence showed water as the source of the illness (Rahman et al., 2019).

It is widely supported in literature (Aji et al., 2017) that many years of neglect by the government and inadequate investment has left the public drinking water supply in many nations in an unreliable state. The society has therefore taken several adaptive measures of alleviating this stress. Globally, about 1.8 billion people are noted for use of unsafe source of water that is polluted by faeces signified respectively by 53% and 35% incidence in Africa and South-East Asia (Boyi et al., 2017). It has been estimated that every year, nearly 1 million people die due to waterborne diseases. In addition, around 37.7 million are affected by waterborne diseases, 1.5 million children are estimated to die of diarrhoea alone, and 73 million working days are lost due to waterborne disease annually. In countries with low and middle-income status, diarrhoea-related diseases are the tenth leading cause~~s~~ of death (Pal et al., 2018). Approximately, 11% of child deaths worldwide are attributed to a diarrhoeal disease and of these cases, 88% are caused by unsafe water or improper sanitation (Boyi et al., 2017). This emphasizes the urgent need for scientific researches in the quality of drinking water relevant for informed policy directives and planning in public health.

Water is considered ‘safe’ when it is free from pathogenic agents, free from harmful chemical substances, and pleasant to taste, ideally free from colour and odour, and usable for domestic purposes (Abideen et al., 2020). A drinking water quality may be acceptable when the water just leaves a treatment plant. However, various physical, chemical, and biological contaminations can happen while the water travels through a distribution system. The most common diseases that can be transmitted through water, according to Onuorah et al. (2017), are diarrhoeal diseases such as bacillary dysentery, typhoid, paratyphoid, cholera, salmonellosis, colibacillosis, and amoebiasis.

Diarrhoeal diseases, such as *E. coli* infection and typhoid fever are the very common diseases that happen due to the use of unsafe water. Different groups of individuals with low immunity are more susceptible to waterborne diarrhoeal diseases (Aji et al., 2017). Children and infants are typically vulnerable due to the improperly developed immune system to pathogens related to water borne diseases and other toxic contaminants.

Several studies have investigated the health implications of poor water quality, shedding light on the potential risks and informing preventive measures. In Oludairo and Aiyedun's (2015) study conducted in rural Bangladesh, an assessment was made on the impact of microbial contamination in drinking water on childhood diarrhoea. The study found a strong association between faecal contamination of water sources and the prevalence of diarrhoea among children under five years old. These findings highlight the critical importance of ensuring micro-biologically safe drinking water to prevent water-borne diseases and protect vulnerable populations.

Bacteria can be naturally present in water bodies and coliforms are among the possibly harmful bacteria that may be present in water. However, the World Health Organization recommends that water with any amount of faecal coliforms should not be consumed (World Health Organization, 2017). Faecal characteristics that indicate human or animal wastes in water causing cramps, nausea, diarrhoea, headaches are Enterococci or coliforms. Sometimes contamination of water due to bacteria such as *Salmonella typhi* causes haemolytic uremic syndrome, a serious kidney disease with potential lifelong complications (Abideen et al., 2020). Other such bacteria are *Shigella* species and *Vibrio cholerae*, among others normally causing serious diseases such as cholera, typhoid fever and bacillary dysentery.

Li et al. (2019) in China investigated the health effects of exposure to arsenic-contaminated groundwater. The researchers observed high risks of skin lesions, respiratory diseases, and various cancers among individuals consuming arsenic-contaminated water. Furthermore, emerging contaminants, such as pharmaceuticals and endocrine-disrupting compounds, have raised concerns about their potential health effects through water consumption. Abdullahi et al. (2020) examined the presence of pharmaceutical residues in water sources and evaluated their implications for human health. The researchers identified potential risks associated with chronic exposure to low concentrations of pharmaceuticals, emphasizing the importance of monitoring and regulating these emerging contaminants in water supplies.

Inappropriate level of water quality, resulting from contamination and pollution of water, directly or indirectly causes both public health and economic implications, prominent amongst them might include human deaths, health expenditures, loss of man-days, and low level of productivity for the nation (Abideen et al., 2020).

2.10 Empirical Study

Empirical evidence from literature supports the pertinence of evaluating and analyzing physicochemical and bacteriological properties of sachet water, for its implications to human health. Current challenges facing the world is unavailability of potable water for human consumption. Studies (Pal et al., 2018; Owusu, et al., 2023) affirm that the existence and survival of humans largely depend on the consumption of clean and hygienic water devoid of particles and contamination by microbes, paramount for good health and human growth.

Substantial number of studies (Yumin et al., 2019; Peter et al., 2019; Boadi et al., 2020) have been conducted to analyze physico-chemical properties of sachet water. These studies however have different levels of contaminations in respect of temperature, electrical conductivity, pH, total dissolved solids, total hardness, total alkalinity, nitrate and chloride among others. Iron, calcium, phosphate, fluoride, copper, manganese and other chemical elements and compounds are also often identified with some conforming to global country-specific standards.

Typically, in Ofosu et al. (2020), out of a sample of 20 sachet water commonly sold and consumed in Sunyani, results showed that 70% (350/500) of the consumers indicated that sachet water had taste, 58% (290/500) of them were not enthused when the water had colour. Using smell as an indicator, 71% of the consumers have had an experience with sachet water smell being questionable.

Abideen et al.'s (2020) study analyzing physicochemical and microbiological properties of sachet water showed that some physical parameters such as appearance, colour, taste conformed to the acceptable standards as required by regulatory authority but the pH did not meet standards. However, in Owusu et al. (2023), all the properties including conductivity, total hardness, total dissolved solids, fluoride and heavy metals such as Manganese conformed to acceptable standards.

In line with WHO's definition that improved drinking water sources are sources that are protected from outside contamination, Pal et al. (2018) added that water is said to be safe to drink and usable for domestic purposes when it is free from pathogenic agents, harmful chemical substances, and pleasant to taste. Pal et al. (2018) further aver that using unsafe drinking or bathing water can impose serious risks to human health.

In a bacteriological analysis (Boyi et al., 2017) of sachet water vended in Kano, coliforms were present in six of the water samples with a count of $2.2\text{-}4.3\times10^{1}$ cfu/ml. The isolates were identified as *Staphylococcus aureus*, *Pseudomonas spp*., *Aeromonas spp.* and *Escherichia coli*. Meanwhile, WHO (2017) has suggested that quality drinking water must not contain *Escherichia coli* or thermotolerant coliform bacteria and other opportunistic pathogens such as *Clostridium* and *Klebsiella* species.

It is established from prior research (Yusuf et al., 2015) that lack of purity of sachet drinking water is attributed to unhealthy practices, poor hygiene of vendors, polluted environment, and non-adherence to WHO regulations. For instance, Yusuf et al. (2015) recorded that nine (9) out of the twelve (12) sachet-water samples analyzed in a study have pH values that fell below the WHO standard for drinking water. The total bacterial counts were also higher than what is stipulated to be acceptable for potable water ($1.0 \text{ x } 10^{1}$ cfu/ml) (Yusuf et al., 2015).

Similarly, the isolation of *E. coli* and *Salmonella spp.* in some sachet water samples investigated in Umar et al. (2019) recorded high bacterial counts beyond the standard of safe drinking water set by water and food regulatory bodies, thus giving an indication that if not promptly checked, an outbreak could occur in the near future. Whereas, Owusu et al.'s (2023) physicochemical and microbiological quality analysis of sachet drinking water samples in Kumasi found total dissolved solids and the concentrations of calcium, sodium, potassium, fluoride and magnesium ions within acceptable ranges, microbial analysis revealed that 67% of the samples were contaminated with pathogenic microorganisms including *E. coli* and coliforms. This result suggesting poor microbiological quality. Owusu et al.'s (2023) study concluded that addressing microbial quality is essential to ensure the safety of drinking water in Kumasi.

Health-related challenges associated with the consumption of contaminated water, as highlighted in Abideen et al. (2020), suggest the need to pursue new strategies to enforce compliance with standard practices in the production of packaged (sachet) water. This is because diseases and deaths are tremendous public health hazards associated with the consumption of microbial contaminated packaged water, as evidenced in Abideen et al.'s (2020) study.

Drinking of polluted or unfit water is a serious issue and another way human health is being endangered. This assertion is based on various diseases and life-threatening ailments associated with this menace. In a related study, Onajite et al. (2018) showed that most of the drinking water samples assessed in Nigeria did not comply with the World Health Organization Standard for drinking water with regards to the coliforms and faecal Enterococci, and thus unsafe for human consumption. The study therefore recommended for routine monitoring of the sachet water producing factories, the producing environment, water source, packaging materials and production machines by regulatory agencies. In line with this, Boyi et al. (2017) also recommended for observance of good production practices and regular bacteriological analysis of water samples.

Studies (Pal & Hadush, 2017; Pal et al., 2018) have indicated that globally, the most commonly occurring diseases transmitted through drinking of unsafe water include infectious hepatitis, cholera, bacillary dysentery, typhoid, paratyphoid, salmonellosis, and amoebiasis. Contaminated water may also cause many more bacterial, viral, and parasitic diseases. Peter et al. (2019) added that majority of the diarrheal deaths that occur worldwide are mainly associated with unsafe water drinking, inadequate sanitation, and poor hygiene.

CHAPTER THREE

MATERIALS AND METHODS

3.0 Overview

The current study adopted the quantitative method using measurable numerical data obtained from laboratory results. Quantitative research method as adopted in this study helps to reap its importance of objectivity, deductiveness, ability to test hypothesis and it is appropriate for making generalization (Rahman et al., 2019). Following the analysis of quantitative data, findings are therefore deductive of the results obtained.

3.1 Source of Samples

Sachet water samples were collected from Winneba, a coastal town in the Central Region of Ghana. Its geographical coordinates are approximately 5.3517° N latitude and -0.6231° W longitude. Winneba is bordered to the north by the Gomoa East District, to the east by the Awutu Senya District, and to the west by the Gomoa West District. As of the 2021 Ghana Population and Housing census, Winneba had an estimated population of around 62,000 residents with growth rate of approximately 2.3% per year. Winneba's water supply is managed by the Ghana Water Company Limited (GWCL), which sources water from both surface water and groundwater to meet domestic needs. However, issues like occasionally presumed water contamination have prompted studies and initiatives to improve water quality for residents.

3.2 Study Design and Selection of Samples

The study adopted the experimental design. The brands of sachet water sold at retail points were purposively selected from September to October, 2024. Three (3) samples were taken from each of the eight (8) sachet water brands, purposively selected at the points of retail as soon as they were delivered from the distributors. These were quickly placed in ice chest and transported to the laboratory for analysis. A total of seventy-two (72) sachets of water were taken from retail points in Winneba as samples for the study, twenty-four (24) sachets at each session for three laboratory tests. The samples were immediately transported in an ice-chest to the Central Laboratory of Ghana Water Company, Kumasi for test in line with the set parameters using standard laboratory techniques.

Bottles receiving water from the sachets were washed using a detergent and rinsed thoroughly with de-ionized water. Ten percent (10%) aqueous Nitric acid was then used to rinse each washed bottle to disinfect them. One percent (1%) Potassium permanganate was also used to rinse the bottles to neutralize the acidity of Nitric Acid. The bottles were finally washed with a small amount of the sample, labeled and kept in an ice chest to maintain its temperature and other external influences such as heat. All tests were done in triplicates.

3.3 Experimental methods involving Physical parameters

3.3.1 The pH determination

The pH of each water sample was determined immediately after receiving the sample at the laboratory using pH meter (HACH +PH3). To ensure accurate reading, the instrument was cleaned and calibrated by using pH buffer solutions 4.7 and 10. The electrode of the HACH +PH3 meter was submerged into the water sample, stirred gently to ensure uniformity, then the pH reading was taken when reading stabilized (Abideen et al.,2020).

3.3.2 The Colour determination

The colour of each sample was measured with Palintest Photometer (Hach Company, Loveland, Colorado, USA) in accordance with WHO (2022) standards for drinking water. The instrument was calibrated by de-ironization. The water sample was placed in a clean cuvette and inserted into the photometer. The specified wavelength was read as displayed in Hazen units (HU) or mg Pt/L.

3.3.3 Turbidity determination

The turbidity of the samples was also determined using HACH 2100Q Turbidity meter (Hach Company, Loveland, Colorado, USA). The water samples were collected in a clean, dry cuvette and inserted into the HACH 2100Q. Following the directives in Chatanga et al. (2019), the lid of the instrument was tightly closed to prevent ambient light which affect the measurement. Turbidity values shown on the display were recorded as readings stabilized.

3.3.4 Conductivity determination

The WTW Conductivity Meter 3110 was used to determine conductivity of the water samples. A well-prepared clean conductivity electrode (1413 µS/cm) was completely immersed into the water sample and stirred gently. Conductivity level of the water displayed on the screen in microsiemens per centimeter (µS/cm), were then read when the meter stabilized (Onajite et al., 2018).

3.3.5 Total Dissolved Solides (TDS) determination

A calibrated handheld conductivity meter Basic C30 (Crison Instruments SA, Barcelona, Spain) was used for the determination of the Total Dissolved solids (TDS) of the water samples. This follows the conductometric method which relies on measuring the electrical conductivity of the water to estimate the concentration of dissolved solids (Abdullahi et al., 2020; Chatanga et al., 2019). Having calibrated the meter using a calibration solution 1413 µS/cm standard, TDS Meter Electrode was fully submerged into the water sample and stirred without the sensor touching the container walls or bottom. TDS value displayed on the screen in parts per million (ppm) was read.

3.4 Chemical analysis

3.4.1 Chloride determination

Chloride content was determined by argentometric method. The sample was titrated under neutral conditions with a standard solution of silver nitrate ($AgNO_3$) as the titrant. Fifty milliliters (50 mL) of the water sample was titrated with a 0.0141 N $AgNO_3$ solution while swirling the flask continuously (World Health Organization, 2017).

3.4.2 Total hardness

Total hardness was determined by the EDTA titrimetric method called EDTA titration. Similar to standardized procedures adapted from Abdullahi et al. (2020), 1 ml of Ammonium hydroxide (NH_4OH) as buffer solution was added to 50 ml of sample in a clean conical flask. One gram of Eriochrome Black T indicator was added to the sample in the conical flask, mixed gently and later titrated against 0.01M EDTA (standardized EDTA solution).

3.4.3 Calcium hardness (Ca^{2+}) determination

A 50 ml of water sample was measured with a graduated cylinder and poured into ~~in~~ a conical flask and 1 ml of 1N NaOH was added to it to adjust the pH of water to around 12. One gram of Mureide indicator Powder was added to the water sample. The solution was titrated with 0.01 M of ED TA solution while swirling the conical flask. The Calcium hardness (mg/L as $CaCO_3$) was obtained as: Volume of EDTA (mL) × 20 this in cosonace with the World Health Organization, (2017) guidelines for drinking water.

3.4.4 Magnesium hardness

Calcium and total hardness were determined by EDTA titration method. Magnesium hardness was calculated from the difference between the total hardness and the calcium hardness which is expressed in mg/L The magnesium concentration was obtained by multiplying magnesium hardness by 0.243 (American Public Health Association (APHA), 2017).

3.4.5 Sulphate ions determination

Sulphate ions was also determined using a calibrated DR/2000 spectrophotometer (Hach Company, Loveland, Colorado, USA) set to the wavelength of 450 nm. Barium Chloride ($BaCl_2$) solutions of concentration 1µg/mL were prepared. To each of these was added 10 ml of conditioning reagent (magnesium chloride) and 0.3 g of barium chloride solution. Four standards of concentration 1µg/mL each were prepared and allowed to stand for 45 minutes. The respective absorbance of the solution at 420 nm was determined. From this data a graph of absorbance verses concentration was plotted. A 10 mL volume of conditioning reagent (magnesium chloride) was added to 25 ml of sample. It was followed by the addition of 0.3g of $BaCl_2$ and the mixture was then diluted to 100 ml with double distilled water. Prepared samples were allowed to stand for 45 minutes. The concentrations were determined using the UV-Visible spectrophotometer at 420 nm. A blank without $BaCl_2$ was prepared and run at the same wavelength (Changa et al., 2019).

3.4.6 Phosphate ions determination

Phosphate ions was determined spectrophotometrically, using DR/2000 spectrophotometer (Hach Company, Loveland, Colorado, USA) in accordance with the World Health Organization, (2017) procedures for drinking water. The ascorbic acid method was used with a DR/2000 spectrophotometer set at 880 nm. A series of phosphate standards (0.1, 0.5, 1.0, 2.5, 5.0 mg/L PO_4^{3-}) was first prepared to create a calibration curve, with each standard receiving a mixed reagent (per 100mL) containing ammonium (2.5 mL) molybdate (2.5 g), antimony potassium tartrate (0.25 g), and ascorbic acid (1.0 g) in sulphric acid (50 mL). Once the spectrophotometer calibrated using the absorbance readings of these standards, 10 mL of the water sample was similarly treated with the mixed reagent, allowing the colour to develop for 15 minutes. The sample's absorbance was then measured at 880 nm, and its phosphate concentration was determined by referencing the calibration curve (APHA), 2017).

3.4.7 Alkalinity determination

According to standard procedures by WHO (2022) guidelines guidelines for drinking water, the titration method was used, where the water sample was titrated with sulphuric acid (H_2SO_4), to measure its capacity to neutralize acids. Ten milliliters (10 ml) of water sample was taken, and a few drops of phenolphthalein added to determine the phenolphthalein alkalinity end-point. The sample was then titrated until there was a change of colour from yellow to orange, to mark the endpoint for total alkalinity. The volume of acid used in these steps was recorded, and the alkalinity was calculated in terms of milligrams per liter of calcium carbonate ($CaCO_3$) as follows:

$$\text{Alkalinity (mg/L as } CaCO_3) = \frac{\text{(vol. of acid used (mL)} \times \text{normality of the acid} \times 50{,}000)}{\text{Volume of the water sample (mL)}}$$

3.4.8 Iron determination

Iron concentration in the water samples was determined using the colorimetric method with a spectrophotometer, set to a wavelength of 510 nm (APHA), 2017). A 1 mL of 1,10-phenanthroline as reagent was added to the 25 mL of water sample to react with any ferrous iron (Fe^{2+}) to form a stable orange-red complex, while ensuring any ferric iron (Fe^{3+}) is reduced to ferrous iron for total iron measurement. After allowing the colour to develop over 15 minutes the absorbance of the sample was measured in the spectrophotometer at 510 nm. A calibration curve was prepared using iron standard solutions (0.1, 0.5, 1.0, 2.5, 5.0 mg/L Fe), which allows the absorbance readings of the water sample to be matched to iron concentrations. The sample's iron content was determined by:

$$\text{Concentration} = \frac{\text{Absorbance} - b}{m}$$

Where; m (Slope) quantifying the sensitivity of absorbance, and b is the absorbance value at zero concentration.

3.5 Bacteriological analysis

Bacteriological examination of the samples was conducted by membrane filtration method, suggested as appropriate in Rahman et al. (2019). The membrane filtration method for detecting coliforms involves filtering a 100 ml of water through a sterile membrane filter that captures bacteria on its surface. Once the water sample has been filtered, the membrane was carefully transferred onto a selective culture medium (MacConkey agar) which supports the growth of coliforms while inhibiting non-target organisms. The setup was then incubated at 35–37°C for 24 hours, allowing sufficient time for the bacteria to grow and form visible colonies. After the incubation period, the membrane was examined, and the colonies were counted with a mechanical counter to ensure accuracy, enabling the quantification of bacteria per volume of water tested, providing valuable insights into the water quality. Results of the colony counted was expressed as the number of colony-forming units (CFUs) per 100 mL of the original water sample.

3.5.1 *Enterobacter*

Enterobacter was detected on the MacConkey agar from the membrane filtration method, where it forms pink colonies. A biochemical test was further conducted (Voges-Proskauer test) for acetoin production to help differentiate *Enterobacter* (WHO, 2022).

3.5.2 Coliform

The Most Probable Number (MPN) method was used to determine faecal coliforms in the samples suggested as appropriate in Abdullahi et al., (2019). Serial dilutions of 10^{-1} to 10^{-4} were prepared by picking 1 ml of the sample into 9 ml of sterile distilled water. One milliliter aliquots from each of the dilutions were inoculated into 5 ml of MacConkey Broth and incubated at 44.5°C (±0.2°C) for 18- 24hrs. Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24 h were identified as positive for coliforms. Counts per 100ml were calculated from MPN tables.

3.5.3 *Escherichia Coli* (*E.coli*)

A bright pink or red colouration indicated the presence of *E. coli* following from the membrane filtration method. As a further biochemical test, Indole Test was done by adding Kovacs' reagent to a tryptone broth culture. A red ring indicates indole production, characteristic of *E. coli* (Changa et al., 2019).

3.5.4 *Salmonella*

On examination, colourless or pale colonies with a black center was marked as the presence of *Salmonella* due to hydrogen sulphide (H_2S) production. Inoculate triple sugar iron (TSI) agar was also used to test Hydrogen Sulphide production for a black precipitate to indicate H_2S production, which is characteristic of *Salmonella* (WHO, 2017)

3.6 Data Analysis

Water quality assessment was computed in numerical values and compared against the Water Quality Index (WQI) in Ghana to determine how healthy the water is (Sila, 2019). The results obtained were compared with the secondary data gotten from publications and standards (WHO, 2017) as well as GWCL standards (GS 220: 2024) to ascertain conformity with the international and national guidelines.

3.6.1 Statistical Analysis

Synonymous to the statistical procedures in Sila (2019), experiments were conducted in triplicates and the average data obtained was analyzed using SPSS version 26.0 with Analysis of Variance (ANOVA) and Duncan test with a level of significance set at $p \leq 0.05$ with 95% confidence interval, to evaluate mean differences in data obtained for the water samples.

3.7 Ethical Consideration

It is always important to observe ethical issues in the conduct of research (Rahman et al., 2019). No real brand identification was represented to trace determined properties to actual brand as the study is strictly for academic purposes.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

This chapter analyses and discusses results from the laboratory tests in line with the specific objectives of the study. The analysis therefore began with the physicochemical properties in respect of pH, colour, conductivity, turbidity, total hardness, total dissolved solids (TDS) of sampled sachet water. Laboratory tests were carried in triplicates with strict adherence to ethical and confidentiality standards. This is in conformity with section 4.07 of the American Psychological Association (APA) Code of Ethics, emphasizing the need for confidentiality, including using pseudonyms when real names may reveal participants' identities, thus ensuring ethical integrity in published research (American Psychological Association-APA, 2017). Therefore, brand names were anonymized in this research to avoid bias and to protect proprietary integrity. In consonance with research practice in Onuorah et al. (2017), unique identification codes were therefore assigned to each brand as B1, B2, B3, …………to B8 for all the 8 brands sampled. For the purposes of triplicate laboratory tests, B1S1, B1S2, B1S3 connote the first, second and third samples of brand 1 (B1); B2S1, B2S2, B2S3 also connotes, first, second and third samples of brand 2 (B2). This continues up to B8S1, B8S2, B8S3 connoting first, second and third samples of brand 8 (B8).

4.1 Assessment of Physicochemical properties of water samples

Results of the physicochemical properties of samples of sachet water vended and consumed in Winneba were assessed in respect of pH, colour, conductivity, turbidity, total hardness and total dissolved solids (TDS). Sunday et al. (2021) posit that the presence and extent of concentration of physicochemical components of drinking water matter in ascertaining the extent of quality ascribed to drinking water. Mean values (in 2 decimal places) were therefore calculated as presented in Table 4.1 for analysis. Laboratory results were then compared with both WHO and GSA standards for thorough discussions to understand ~~of~~ the prevailing circumstances in relation to the quality of sachet water being elevated. As a complement to existing literature (Yumin et al., 2019; Onuorah et al., 2017) and in line with research tenets, the analysis and discussion were also made with reference to previous empirical data to ascertain whether or not the current data is in consonance with prior literature.

Table 4.1: Mean Concentration of Physicochemical parameters of Water samples

Physicochemical parameters	**Sachet water brands (Samples)**								**Std. Dev.**	**WHO Standards**	**Ghana Standards (GS 220-2024)**
	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**			
pH	6.89	6.96	7.13	7.21	7.09	7.24	6.95	6.99	0.13	6.5-8.5	6.5 – 8.5
Colour (HU)	0	0	0	0	0	0	0	0	0.00	5.0	5.0
Conductivity (µS/cm)	31.87	42.80	30.67	27.40	35.47	147.87	42.87	23.63	40.99	1000	1000
Turbidity (NTU)	0.68	0.50	0.38	0.41	0.62	0.45	0.45	1.35	0.31	5.0	5.0
Total hardness (mg/L)	1.67	1.67	2.00	1.33	2.00	4.67	2.00	1.33	1.08	500	500
Total dissolved solids (TDS)	16.70	22.27	16.40	14.33	18.07	74.10	21.83	12.57	20.30	500	500

Source: Field Data Laboratory Analysis, 2024

Table 4.2: ANOVA on Physicochemical properties

Parameters		Sum of Squares	df	Mean Square	F	Sig.
pH level of Water sample	Between Groups	.117	7	.017	.	.
	Within Groups	.000	0	.		
	Total	**.117**	**7**			
Electrical Conductivity (µS/cm)	Between Groups	11762.885	7	1680.412	.	.
	Within Groups	.000	0	.		
	Total	**11762.885**	**7**			
Total Disolve Solids (mg/L)	Between Groups	2885.801	7	412.257	.	.
	Within Groups	.000	0	.		
	Total	2885.801	7			
Turbidity (NTU)	Between Groups	.679	7	.097	.	.
	Within Groups	.000	0	.		
	Total	**.679**	**7**			
Hardness (mg/L)	Between Groups	8.188	7	1.170	.	.
	Within Groups	.000	0	.		
	Total	**8.188**	**7**			
Colour (Hazen Unit)	Between Groups	.000	7	.000	.	.
	Within Groups	.000	0	.		
	Total	**.000**	**7**			

pH Results

The acidity or alkalinity of drinking water, which is measured by its pH, has a significant impact on its taste, corrosivity, and general suitability for human consumption. Table 4.1 shows the pH values for the sachet water brands, ranging from 6.89 (B1) to 7.24 (B6). All the samples analyzed had pH values within the permissible range of 6.5 to 8.5, as recommended by the Ghana Standards (GS 220:2024) and World Health Organization (WHO) guidelines.

Among the brands tested, B6 had the highest pH value of 7.24 pH units, indicating slightly increased alkalinity, whereas B1 had the lowest pH value of 6.89 pH units, which is closer to neutrality. These variances are common and could result from treatment procedures or the natural makeup of the source water. Metals can be released into the water when metallic water containers corrode at pH values below 7.0. In order to prevent corrosion of distribution systems and guarantee the water's palatability, pH must be kept within an acceptable range. The solubility and types of ions that are present in water greatly influence the toxicity of water.

The result (6.89 to 7.24 pH unit) aligns closely with Boakye et al. (2021) in sachet water quality assessment in Ghana which reported pH values ranging between 6.8 and 7.4. Further confirming the consistency of these findings, Nyarko and Oduro-Kwarteng (2023) found that the majority of sachet water brands in urban communities in Ghana had pH values within the WHO and Ghana Standards range.

Colour examination

Water's colour serves as an aesthetic indicator of the presence of metals, organic materials, and other impurities. The maximum permissible limit of five (5) Hazen units is specified in both the WHO and Ghana Standards. Every brand had a colour value of 0, which indicates superior clarity and the lack of discoloration. The consistent outcomes for all sachet water brands points to efficient treatment procedures, suggesting effective filtration and disinfection techniques. This is also consistent with Ghanaian consumers' growing focus on aesthetic quality, as evidenced in Boakye et al. (2021). Although not always directly hazardous to human health, water colour is a crucial sign of possible contamination.

Electrical Conductivity of Water

Conductivity is a measure of the capacity of water to conduct electricity and is correlated with the concentration of dissolved ionic compounds (Peter et al. (2019), including minerals and salts. The conductivity of the sachet water samples tested here ranged from 23.63 µS/cm to 147.87 µS/cm. Though at variance, but comparable with that of Sunday et al. (2021) in which conductivity levels ranged from 77.2 µS/cm to 133 µS/cm among 8 sachet water brands, all of them fell far below the maximum limit of 1000 µS/cm that is recommended by the WHO and Ghana Standards. Similar trends were seen in Indian studies, (Kumar & Purohit, 2020) which found that bottled water had conductivity levels ranging from 15 µS/cm to 150 µS/cm.

Water sample B8 had the lowest conductivity value of 23.63 µS/cm, which indicates that there are not many dissolved ions which is frequently linked to high-purity water. In contrast, sample B6 had the greatest conductivity value (147.87 µS/cm), which suggests that it had a comparatively higher amount of minerals. Higher conductivity in B6 may improve the water’s flavour and appeal to customers who like water with trace minerals. While all values are safe, higher conductivity in B6 may enhance the water’s taste, potentially appealing to consumers who prefer water with trace minerals.

Turbidity

One important measure of clarity of water is turbidity, which indicates the presence of suspended particles in the water such as clay, silt, organic matter, and microorganisms. According to WHO recommendations, drinking water can have a maximum turbidity of 5.0 NTU. The sachet water brands had turbidities that were significantly below the threshold, ranging from 0.38 NTU (B3) to 1.35 NTU (B8).

Superior filtration procedures are probably the reason for the remarkable clarity of water sample B3, which had the lowest turbidity. However, sample B8 remained within permissible bounds despite having the greatest turbidity of all the brands. Any water sample with elevated turbidity should be monitored since it could be a sign of possible contamination or ineffective treatment procedures. High turbidity levels are often believed to signal a high likelihood of problems since they may make it difficult to effectively disinfect the water against harmful microorganism contamination.

Total Hardness

Total hardness is a measure of the concentration of calcium and magnesium ions, which can change the flavour of water and how it interacts with soap. The Ghana Standards adhere to the WHO’s recommendation that drinking water have a hardness level of less than 500 mg/L. The total hardness in this study ranged from 1.33 mg/L (B4, B8) to 4.67 mg/L (B6), all of which were significantly below the limit, which is consistent with the result in Asare et al. (2020).

A similar alignment can be found in Anaba et al. (2022), who also found that the mean total hardness levels of the sachet water samples in Kumasi were low and under the Ghana Standards threshold. Scaling in pipes and household appliances is less likely due to the softness of the water samples indicated by the low hardness levels. While B6, which has the highest hardness, may taste a little more mineral, the water samples B4 and B8, which have the lowest hardness levels, may be perceived as having a lighter and more neutral flavour.

Total Dissolved Solids (TDS) Analysis

The TDS measurement was used to determine the total amount of all organic and inorganic components, such as minerals, salt, metals, and other particles, dissolved in water. WHO standards recommend TDS values below 500 mg/L, but the Ghana Standards allow for 500 mg/L same as WHO (Olowe et al., 2016). The sachet water samples had TDS levels that were all within permissible limits, ranging from 12.57 mg/L (B8) to 74.10 mg/L (B6). Sample B8 which has the lowest TDS, is light and hence depicts water with minimal dissolved salts. Sample B6, which had the greatest TDS, would appeal to consumers seeking more flavoured water due to its slightly greater mineral content. The amount of TDS in drinking water affects the water's flavour, safety, and appearance.

According to Oluwabunmi et al. (2018), the water's low TDS value of B8 suggests that it has few dissolved solids, making it comparatively pure and devoid of minerals or contaminants. Low-TDS water is a popular option for people who prefer a softer flavour because consumers frequently view it as lighter and more refreshing. But according to Oluwabunmi et al. (2018), very low TDS levels can occasionally lead to water that tastes bad because it lacks vital minerals like calcium and magnesium. The water may have undergone substantial purification procedures like reverse osmosis, which might remove essential minerals.

Although it is still well within safe bounds, the higher TDS value in B6 indicates a larger concentration of dissolved salts and minerals. The slightly increased taste that some consumers prefer often referred to as "mineral-rich" water may be caused by this level of TDS. According to Oluwabunmi et al. (2018), trace minerals like calcium, magnesium, and potassium which are critical for bone health and metabolic processes may be present at moderate TDS levels. Water with comparatively greater TDS may eventually produce slight scaling in equipment like kettles and coffee makers, even if it is within permissible bounds.

The TDS levels found in this study are consistent with findings from earlier studies on the quality of sachet water in Ghana and other underdeveloped nations. Owusu et al. (2023), for example, discovered that TDS levels in sachet water samples met GSA approved requirements, which is consistent with the results in this study. These investigations found that substantial purification techniques used during production to guarantee adherence to customer preferences and regulatory norms result in low TDS levels in sachet water.

This suggests that although low TDS water is typically safe to drink, it can be deficient in vital minerals that support hydration and general health. Long-term use of demineralized water may result in mineral deficits, according to Boyi et al. (2017). Because they provide vital trace elements that support physiological activities, moderate TDS levels, such as those found in B6, can be advantageous. Additionally, water with extremely low TDS, like B8, might be viewed as less palatable or gratifying, which could affect customer choice.

However, people who are used to mineralized water may favour B6 because of its somewhat higher mineral concentration, which may provide a deeper taste sensation. Because it doesn't change the flavour of food or beverages, low TDS water is perfect for domestic uses like cooking and beverage making. In regions where mineral deficits are prevalent, higher TDS water, like B6, may be favoured even though it may cause mild scaling in household appliances (Boyi et al., 2017).

The TDS levels found in all of the sachet water brands are well within legal bounds and show that the water is of a high calibre that satisfies Ghanaian and WHO standards. Brand-to-brand variations in TDS readings point to variations in water sources and treatment techniques. Moderate TDS levels improve taste and offer trace minerals that may be good for customers' health, but lower TDS levels signify greater purity.

The descriptive statistics run provided insights into the variability and central tendencies of the measured physicochemical properties of sachet water samples, as shown in Table 4.3.

Table 4.3: Descriptive Statistics on Physicochemical properties of water samples

	Number of Samples	Minimum	Maximum	Mean	Std. Deviation	Variance
pH level of Water sample	24	6.89	7.24	7.0575	0.12903	0.017
Electrical Conductivity (µS/cm)	24	23.63	147.87	47.8225	40.99283	1680.412
Total dissolved Solids (mg/L)	24	12.57	74.10	24.5337	20.30412	412.257
Turbidity (NTU)	24	0.38	1.33	0.6025	0.31148	0.097
Hardness (mg/L)	24	1.33	4.67	2.0837	1.08156	1.170
Valid N (listwise)	24					

Source: Field Data, 2025

The sachet water samples' pH readings, which vary from neutral to slightly alkaline, are within the permitted WHO and Ghana Standards range of 6.5 to 8.5. The low variance (0.017) and standard deviation (0.12903) indicate that there is little fluctuation in the pH levels across the brands. Water that has a neutral pH (around 7.0) is more palatable and is less likely to corrode in pipes and water storage systems.

Low mineralization is indicated by the mean conductivity of 47.8225 µS/cm, which is well below the 1000 µS/cm WHO and Ghana standard. But the high variance

(1680.41) and standard deviation (40.99) point to notable variations amongst the brands, especially as brand B6 has the highest conductivity (147.87 µS/cm), which might be a symptom of a higher mineral content.

Comparing the mean result of 24.53 mg/L to the WHO recommendation limit of 500 mg/L, the dissolved solids are extremely low. The high standard deviation (20.30) and broad range (12.57–74.10 mg/L) indicate brand diversity, with B6 having the highest TDS (74.10 mg/L), possibly as a result of a higher mineral content. While some people may find greater TDS to be more palatable, lower TDS water is frequently thought to taste lighter.

The sachet water samples generally show good clarity, as evidenced by the average turbidity of 0.6025 NTU, which is significantly lower than the WHO and Ghana norm of 5 NTU. Although still within safe bounds, one sample (B8) exhibited a comparatively greater turbidity (1.33 NTU), which ~~would~~ indicate the presence of particulate debris. There is some variation in trademark clarity, as indicated by the moderate standard deviation (0.31148). However, the ANOVA test (table 4.2) run indicated that there is no measurable significant variation within the individual sachet water brands. This was evident from the basis that the sum of squares for the within-group variation was 0.000, and the degrees of freedom (df) for the within-group category was zero in all cases.

4.2 Determination of the level of Minerals in Sachet water samples

The minerals content in the sampled sachet water were also determined in respect of Calcium, Magnesium, Iron, Sodium, Chloride, Sulphate and Phosphate. Yumin et al. (2019) opine that the existence of these minerals might not necessarily indicate contamination with adverse effect on human health, but over concentration is a matter of concern for informed policy directives towards safeguarding human health. Once again, mean values were ascertained from the triplicate laboratory tests results and compared with regulatory standards (WHO and GWCL) to determine acceptability of water samples for human consumption. The laboratory results have been presented in Table 4.3 for analysis and discussion.

Table 4.4: Mean Concentration of Mineral contaminants in Sachet water samples

Mineral contents	Sachet water brands (Samples)								Std. Dev	Sig.	WHO Standards	GWCL (GS)
	B1	B2	B3	B4	B5	B6	B7	B8				
Calcium (mg/L)	0.44	0.40	0.43	0.31	0.37	1.25	0.48	0.32	.43699	$.127^{a}$	75	200
Magnesium (mg/L)	0.13	0.16	0.22	0.14	0.26	0.38	0.20	0.13	.11652	$.098^{a}$	50	150
Iron (mg/L)	0.02	0.00	0.01	0.00	0.01	0.04	0.00	0.00	.01829	$.162^{a}$	0.1	0.30
Chloride (mg/L)	12.7	13.3	11.3	13.7	9.7	17.7	10.7	10.0	7.07606	$.932^{a}$	200	250
Sulphate (mg/L)	0.38	2.10	2.57	0.25	1.92	0.79	1.56	1.09	2.06584	$.884^{a}$	500	250
Phosphate (mg/L)	0.38	0.11	0.21	0.17	0.18	0.19	0.18	0.32	.21193	$.877^{a}$	1.0	

Source: Field Data Laboratory Analysis, 2025. Minerals with same superscript have no significant mean differences

Mineral pollutants in drinking water have an impact on taste and health, making them crucial markers of water quality. Iron and sulphates, for instance, can have negative consequences when present in excess, whereas other minerals, like calcium and magnesium, are good for human health. The Ghana Standards (GS 220-2024) and the World Health Organization (WHO) have set acceptable levels for these minerals to guarantee safety. The mineral concentrations in the sachet water samples (B1–B8), as observed in Table 4.3, varied depending on the brand, but all results were within the recommended ranges, indicating that they are safe for drinking.

Calcium Content (Ca^{2+})

Calcium is an essential mineral for nerve transmission, muscular contraction, and bone formation. It dissolves in water from natural sources like gypsum and limestone. Calcium contents in the examined sachet water samples ranged from 0.31 mg/L in B4 to 1.25 mg/L in B6. The sample B6 had the highest concentration (1.25 mg/L), indicating a significantly higher calcium presence, B4 had the lowest concentration (0.31 mg/L). Given that these results are much below the allowable limits, the sachet water is clearly very soft and devoid of considerable mineralization.

Similar low calcium amounts, usually between 0.2 mg/L and 2.5 mg/L, have been observed in studies on the quality of sachet water in Ghana, such as that conducted by Nyarko et al. (2022). The measured amounts are in line with Anaba et al. (2022) and imply that the majority of sachet water is purified by removing extra minerals, which results in a softer, lighter flavour, which lessen scaling in pipes and appliances, However, it may also limit the amount of calcium that is consumed through food, particularly for populations who depend on drinking water as a supply of minerals. Although low calcium levels guarantee that the water does not cause scaling in domestic appliances, by implication, they may also deprive users of a necessary dietary mineral.

Content of Magnesium (Mg^{2+})

Magnesium has a vital role in cardiovascular health, enzyme activity, and muscle contractions. Ghana Standards allow a maximum of 150 mg/L in drinking water. The sachet water samples' magnesium concentrations varied from 0.13 mg/L in B1 to 0.38 mg/L in B6. The maximum concentration of magnesium detected (0.38 mg/L) in sample B6 is below the allowable limit, confirming that all the sachet water samples contain very low levels magnesium.

A similar tendency of low mineralization was confirmed by Addo et al. (2020), who discovered magnesium levels in sachet water varying between 0.10 mg/L and 0.50 mg/L. While low-magnesium soft water keeps plumbing systems from scaling, it might not make a substantial contribution to daily magnesium consumption. People who primarily get their magnesium from sachet water may require other dietary sources of magnesium because magnesium shortage is associated with cardiovascular risks and cramping in the muscles (Onuorah et al., 2017).

Iron (Fe^{2+}/Fe^{3+}) Content

Although iron is found naturally in groundwater, it can also be caused by industrial contamination or pipe corrosion. Iron is necessary for the production of red blood cells, but Abdullahi et al. (2020) share the knowledge that too much of it stains, encourages the growth of bacteria, and has an unpleasant metallic taste. Given the varying levels of concentration of Iron in the samples, from a minimum of 0.00 mg/L (B2, B4, B7, and B8) to a maximum of 0.05 mg/L (B1), all the sachet water are found within the safety limit. This is because Ghana Standards permit up to 0.30 mg/L of iron.

Even B1's greatest concentration (0.05 mg/L) is much below the allowable limits. Some brands' total lack of iron indicates effective filtration and treatment procedures, which lowers the possibility of metallic taste or colouring in the water. Similar iron levels, usually ranging from 0.01 mg/L to 0.06 mg/L, were realized in earlier studies on sachet water quality in Ghana (Bempah et al., 2021). This is a sign of effective water treatment methods, which guarantee that the water will continue to be visually pleasing and free of iron-related problems.

Chloride (Cl^-) Content

In addition to being naturally found in water, chloride is also introduced via sewage and salt runoff from roads. Low amounts of chloride are safe, but high concentrations can corrode metal pipes and give food a salty taste. At the permissible levels of up to 250 mg/L (Ghana Standards), chloride values in the sachet water samples ranging from 9.7 mg/L (B5) to 17.7 mg/L (B6) are safe for drinking. These results are consistent with Darko et al.'s (2019) research results, which recorded chloride concentrations in sachet water ranging from 5 mg/L to 25 mg/L. The low chloride values indicate~~s~~ that the sachet water samples are not overly contaminated with salt. Abdullahi et al. (2020) sees this as ideal since high levels of chloride make water more corrosive, which damages infrastructure and piping. These samples' mild levels suggest that the water is safe and tastes well.

Sulphate Content (SO_4^{2-})

Because of fertilizers, industrial pollutants, and rock weathering, sulphates naturally occur in water. When taken in excess, they may have a disagreeable taste and laxative effects (Yumin et al., 2019). Ghana Standards recommends a maximum of 250 mg/L, levels in the sachet water samples varied from 2.30 mg/L (B3) to 0.00 mg/L (B1, B4), with the sample B3 having the greatest value (2.30 mg/L) which is well below the allowable limits and suggests very little sulphate contamination. Sulphate contamination is not seen as a major problem amongst the sachet water under study, thus collaborating Annan et al's. (2021) finding on the subject, which found equally low sulphate levels below 5 mg/L. According to these results, there is little chance that the sachet water would have any laxative or gastrointestinal side effects, making it safe for people of all ages to use.

Content of Phosphate (PO_4^{3-})

Detergents, industrial waste, and agricultural fertilizers are the main sources of phosphates in water. It is established in literature (Li et al., 2019) that low amounts do not immediately endanger human health, but large concentrations can cause eutrophication, which is the process by which water bodies become too populated with algae. Ghana lacks a precise phosphate content requirement, while the WHO sets the maximum allowable level at 1.0 mg/L (Li et al., 2019).

Among the sachet water brands, the phosphate contents varied from 0.14 mg/L (B8) to 0.61 mg/L (B1). Phosphate levels were lowest in sample B8 (0.14 mg/L) and highest in sample B1 (0.61 mg/L), all of which are within the acceptable level as per WHO recommendations. This indicates that there is very little phosphate pollution amongst sachet water vended in the study setting (Winneba). The conclusion that phosphate contamination is not a significant hazard for packaged water is supported by earlier research in Osei et al. (2022).

All measured parameters, according to the analysis of mineral pollutants in sachet water samples, are within the bounds of the Ghana Standards and WHO. The lack of noticeable iron and sulphate pollution suggests acceptable water quality, while the low calcium and magnesium contents imply that the sachet water is soft. The findings support the constancy of sachet water quality and are consistent with earlier research (Li et al., 2019; Onuorah et al., 2017) carried out in Ghana. Differences in source water composition and treatment methods are reflected in the discrepancies seen among brands. Although the sachet water is safe to drink, people who depend on it as their only source of minerals may need to find other dietary sources of important minerals like calcium and magnesium due to its low mineral concentration. Descriptive statistics was run on mineral content of the sachet water samples for analysis to understand variations in key parameters across different brands, as shown in Table 4.4.

Table 4.5: Descriptive Statistics on Mineral contents of water samples

	Number of Samples	Minimum	Maximum	Mean	Std. Deviation	Variance
Calcium	24	0.20	2.40	.5026	.43699	0.095
Magnesium	24	0.05	0.49	.2013	.11652	23.767
Iron	24	0.00	0.08	.0096	.01829	0.000
Chloride	24	4.00	28.00	12.3750	7.07606	7.268
Sulphate	24	0.00	7.00	1.3312	2.06584	0.752
Phosphate	24	0.00	0.80	.21193	.13938	0.019
Valid N (listwise)	24					

Source: Field Data, 2025

The calcium content had an average of 0.5013 mg/L with a standard deviation of 0.30838, indicating that the calcium levels were relatively stable across the samples.

There was minimal variation, which suggests that all the sachet water brands generally contained similar amounts of calcium. This low variation in calcium is beneficial as it indicates consistency in the quality of water across different brands. With a mean of 1.9363 mg/L a standard deviation of 4.87516**,** and a variance of 23.767**,** the results indicate substantial variability in magnesium concentrations across the samples. This high variability suggests that some brands had notably higher magnesium levels than others.

Given a mean of 0.0138 mg/L and the standard deviation of 0.01996**,** the results indicate minimal variation in iron concentration. This suggests that iron content in the sachet water was quite low and consistent across all brands. With a mean value of 12.2625 mg/L**,** and a standard deviation of 2.69600**,** a moderate variation in chloride concentration is indicated. Although there is some variation in chloride content, all the samples remained within safe limits for drinking water. Sulphate levels ranged from 0.00 mg/L to 2.30 mg/L**,** with a mean of 1.1213 mg/L**.** The standard deviation was 0.86696, showing moderate variation. Phosphate concentrations had a mean of 0.3338 mg/L across all samples**.** The standard deviation was 0.13938**,** showing relatively low variation. This indicates that the phosphate content was fairly consistent across the different brands.

4.3 Analysis of Bacteriological quality of sachet water samples

Since the presence of bacteria like *Salmonella spp*., *E. coli*, total coliforms, and *Enterobacter spp*. can suggest pollution and possible health hazards, it is imperative for public health to ensure the microbiological safety of drinking water. Zero tolerance for certain bacterial pollutants in drinking water is established by the Ghana Standards Authority (GS 220-2024) and the World Health Organization (WHO, 2022). The study's findings suggest that different sachet water brands have differing degrees of microbiological contamination, which calls into question the efficacy of water treatment and hygiene procedures. Table 4.5 indicates the mean counts of the various bacteria under investigation resulting from the triplicate laboratory tests.

Table 4.6: Bacterial Count in Sachet Water Samples

	Bacterial presence					
Sample	**Total Coliform (cfu/100mgL)**	**E-Coli (cfu/100mgL)**	**Salmonella *spp* (cfu/100mgL)**	**Enterobacter *spp* (cfu/100mgL)**	**F**	**Sig. ($P \leq 0.05$)**
B1	$102.7^{a} \pm 77.39$	0	0	$43.0^{a} \pm 75.06$	.333	$.667^{a}$
B2	$154.0^{a} \pm 180.08$	0	0	0.0 ± 0.00		
B3	0 ± 0.00	0	0	0.0 ± 00		
B4	$7.3^{a} \pm 12.70$	0	0	0.0 ± 00		
B5	$11.3^{a} \pm 19.63$	0	0	$17.0^{a} \pm 30.02$	.333	$.667^{a}$
B6	$17.7^{a} \pm 18.01$	0	0	$333.0^{a} \pm 557.14$	.333	$.667^{a}$
B7	$61.3^{a} \pm 64.17$	0	0	0.0 ± 0.00		
B8	0 ± 0.00	0	0	$92.0^{a} \pm 159.35$	.333	$.667^{a}$
WHO	0	0	0	0		
GWCL	0	0	0	0		

Source: Field Data, 2025. Bacteria contamination levels with same superscript have no significant mean differences

Total Coliforms

The large class of bacteria known as total coliform bacteria is often found in the environment, including water surface and in faecal matter. Their presence in drinking water raises the possibility of contamination and insufficient disinfection, even if they are not always harmful. WHO and Ghana Standards (GS 220-2024) state that safe drinking water should have zero cfu/100 mL of total coliforms.

The overall coliform levels in the sachet water samples differed, but were not statistically significant at $p \leq 0.05$. The microbiological safety standards set by the WHO and Ghana were met by samples B3 and B8, which had a cfu/100 mL reading of 0. The samples with the highest coliform counts were B2 (154 cfu/100 mL), B1 (102.7 cfu/100 mL), B7 (61.3 cfu/100 mL), and B6 (17.7 cfu/100 mL). These values show possible contamination during processing, packing, or storage since they are higher than the allowable limits. Despite being lower than some other brands, B4 (7.3 cfu/100 mL) and B5 (11.3 cfu/100 mL) still did not meet safety criteria for coliform.

These brands' coliform content raises the possibility of post-treatment contamination from improper handling or packaging, contamination from raw water sources, or insufficient filtration. Previous studies conducted in Ghana (Boadi et al., 2020) revealed comparable levels of coliform contamination in 85% of the water samples with both total and faecal coliforms with water quality index calculated at 54.25. This confirms worries regarding variations in water purifying methods across producers.

E. coli

The presence of *E. coli* in drinking water indicates a high risk of waterborne illnesses like cholera, typhoid fever, and diarrhea. It is also a direct signal of faecal contamination. *E. coli* levels in drinking water must be nil (0 cfu/100 mL) according to both WHO and Ghana Standards. According to the findings, none of the sachet water samples had *E. coli*, which is in compliance with Ghanaian and WHO water quality standards. Even in samples with high coliform counts, the lack of *E. coli* indicates that direct any faecal contamination was successfully removed by the treatment procedures. This result is consistent with the results in Nyarko et al. (2022), which found that Ghana had a comparatively low level of *E. coli* contamination in sachet water.

Salmonella species

Salmonella species are harmful bacteria that can lead to severe illnesses including salmonellosis and typhoid fever (Li et al., 2019). Because of the serious health hazards that come with having *Salmonella spp.* in drinking water, the WHO and Ghana Standards call for a zero tolerance (0 cfu/100 mL). There was no direct health risk from *Salmonella spp*. in any of the studied samples, as all sachet water brands contained no *Salmonella* (0 cfu/100mL). Disinfection techniques were successful in getting rid of *Salmonella spp.* contamination.

Enterobacter spp.

Enterobacter species are frequently found in soil, water, and human intestines. They belong to the total coliform group. Although not usually harmful, some species can infect people, especially those with weakened immune systems. Zero *Enterobacter spp.* (0 cfu/100 mL) in drinking water is recommended by the WHO and Ghana Standards.

B6 had the highest *Enterobacter* count (333 cfu/100 mL), which is a serious public health concern. The brands B1 (43 cfu/100 mL), B8 (92 cfu/100 mL), and B5 (17 cfu/100 mL) are also noted for their *Enterobacter spp*. contamination. These findings, which are above WHO and Ghanaian standards, suggest that there may have been contamination during packaging or storage. With a microbiological safety rating of 0 cfu/100 mL, brands B2, B3, B4, and B7 were found to be in compliance. The results are in line with research by Osei et al. (2022), who found that inadequate hygienic procedures during the bottling and packing processes were connected to *Enterobacter* contamination in a few Ghanaian sachet water brands.

High levels of *Enterobacter spp*. and total *coliform* in some sachet water brands pose serious health concerns to the general public, especially to susceptible groups like young children, the elderly, and people with compromised immune systems. Diarrhoea diseases, gastrointestinal infections, and other waterborne illnesses are largely caused by contaminated drinking water. These illnesses can have serious health effects, such as dehydration, malnutrition, and in the worst situations, death (Falnyi, et al., 2022). The results highlight how urgently microbial contamination in sachet water must be addressed in order to safeguard the public's health and stop waterborne disease epidemics.

The finding of higher levels of *coliform* and *Enterobacter spp*. in brands B1, B2, B5, B6, B7, and B8 raises concerns about regulatory irregularities in quality control procedures in the sachet water sector. These brands expose weaknesses in oversight and enforcement as they do not adhere to the Ghana Standards Authority's and the World Health Organization's (WHO) microbiological standards. Nonetheless, the study found no significant mean differences in microbial count (appendixes A & B) amongst the brands tested.

To guarantee that all manufacturers of sachet water follow correct hygiene procedures, carry out regular microbial testing, and take corrective action when contamination is found, stricter regulatory monitoring is required. The hazards of microbiological contamination can be reduced by bolstering surveillance systems and enforcing adherence to water quality standards. The presence of coliforms and *Enterobacter spp* may also result from inadequate filtration procedures, poor sanitation measures, or inappropriate storage conditions (Onuorah et al., 2017). To get rid of microbiological pollutants, water treatment facilities and manufacturers of sachet water need to implement stricter filtering and chlorination methods.

4.4 Evaluation of Human health risk associated with the quality of Sachet water

Although majority of the sachet water brands examined were within acceptable WHO and Ghana Standards (GS 220-2024), some variances may have negative health effects based on personal sensitivity and extended intake. Drinking water's pH has an impact on its flavour, corrosiveness, and possible health consequences. The pH values of the tested sachet water brands ranged from 6.89 (B1) to 7.24 (B6), which is within the 6.5–8.5 range that the WHO recommends. Water with a low pH can leach metals (including lead and copper) from pipes and storage containers, raising the danger of heavy metal poisoning, even though none of the samples had an acidic pH ($pH < 6.5$). Kidney disease, developmental delays in children and neurological harm are all associated with prolonged exposure to lead in drinking water (WHO, 2022). Although the highest recorded pH in this study was 7.24 (B6), excessive alkalinity ($pH > 8.5$) in drinking water can cause digestive issues and affect the body's electrolyte balance**.**

According to Sunday et al. (2021), electrical conductivity in water is a measure of the concentration of dissolved ions, including potentially hazardous heavy metals or industrial contaminants, as well as necessary minerals like calcium, magnesium, and sodium. Mineral deficits resulting from extremely low mineral content in water (less than 30 µS/cm) can impact bone health and electrolyte balance (González et al., 2021). With a TDS level of 12.57 mg/L, sample B8 highlights concerns raised by Osei et al. (2022) that prolonged consumption of water low in dissolved solids can result in electrolyte imbalance and increase the risk of dehydration and nutrient deficits. According to earlier research by Nyarko et al. (2022), sachet water brands with low TDS levels may not be able to replace vital minerals lost via perspiration and urination if they are taken exclusively.

Taste and usability of water are influenced by its total hardness, which gauges the amount of calcium and magnesium ions present. According to Onuorah et al. (2017), drinking water that is somewhat hard may lower the incidence of cardiovascular illnesses by supplying vital minerals. However, if ingested over an extended period of time, very low hardness (as observed in samples B4 and B8) may result in mineral deficiencies. Asare et al. (2020) further report that soft water has the potential to be more caustic and to release heavy metals like copper and lead into drinking water through pipes.

The comparatively low calcium content, which ranges from 0.31 mg/L (B4) to 1.25 mg/L (B6), has ramifications for consumer health since it is acknowledged that calcium is a necessary mineral for bone health, muscle function, and cardiovascular control. According to González et al. (2021), kids who drink extremely soft water, may not be getting enough calcium from which raises their risk of dental cavities and weakening of their enamel.

Beyond the physicochemical and mineral properties of the sachet water under study, microbial contamination poses the most significant health risk in sachet water consumption. Prior studies in Ghana (Nyarko et al., 2022) have reported instances of total coliform and *Enterobacter spp*. contamination in some sachet water brands, indicating poor sanitation practices. *Enterobacter spp*., though not always pathogenic, can pose serious risks to immunocompromised individuals, potentially causing urinary tract infections, pneumonia, and bloodstream infections (Osei et al., 2022).

The samples B2 (154 cfu/100 mL), B1 (102.7 cfu/100 mL), B7 (61.3 cfu/100 mL), and B6 (17.7 cfu/100 mL) were the samples with the highest coliform levels. Since these readings exceed the permitted limits, they may indicate contamination during processing, packing, or storage. Samples B4 (7.3 cfu/100 mL) and B5 (11.3 cfu/100 mL) did not fulfill safety requirements for coliform, even though their levels were lower than the other brands. Notable for their *Enterobacter spp.* contamination are the brands B1 (43 cfu/100 mL), B8 (92 cfu/100 mL), and B5 (17 cfu/100 mL). As a major public health concern however, Sample B6 showed the highest Enterobacter count (333 cfu/100 mL). Acute gastroenteritis can result from toxins produced by Enterobacter species that irritate the gastrointestinal system (Nyarko et al., 2022). Infants, young children, the elderly, and people with compromised immune systems are high-risk vulnerable groups.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSIONS, RECOMMENDATIONS AND SUGGESTION FOR FUTURE STUDY

5.0 Overview

The study was conducted to assess the quality of selected brands of sachet water vended in Winneba, Ghana. A total of seventy-two (72) sachets of water for eight (8) brands were taken from retail points as samples for laboratory tests at different times. The tests involved the evaluation of physicochemical properties, mineral concentrations and bacteriological quality associated with the sachet water brands.

5.1 Summary of Findings

Thematically, these summaries can be made as findings from the analysis of the study's results:

5.1.1 Physicochemical properties

The pH levels of the various sachet waters ranged from 6.89 to 7.24. All the values were within the permissible range as set by the WHO and Ghana standards. This implies that the water is neutral to slightly alkaline and can be consumed without health risks. All the values were above zero, which implies an improved level of transparency as the sachet waters had zero units of color hazen. This implies there is no tendency for the water to get discolored. The use of good filtration and disinfection practices can be attributed to consumer preferences for high aesthetic qualities in the water they consume in Ghana. The electrical conductivity levels ranged from 23.63 µS/cm as recorded in B8 to 147.87 µS/cm as recorded in B6. All the values were below the limit set by the Ghanaian Standard and the WHO of 1000 µS/cm. The low conductivity reading implies a high level of purity in the water as there is a low concentration of dissolved ions from the water sources in Ghana.

The turbidity of the sachet water samples ranged from 0.38 NTU (B3) to 1.35 NTU (B8), all well below the WHO limit of 5.0 NTU, indicating good water clarity. The lowest turbidity in B3 suggests effective filtration, while B8, despite having the highest turbidity, remained within safe limits. Although all values are acceptable, elevated turbidity can indicate potential contamination risks or inadequate treatment, necessitating regular monitoring. The total hardness of the sachet water samples ranged from 1.33 mg/L (B4, B8) to 4.67 mg/L (B6), all well below the WHO and Ghana Standards limit of 500 mg/L, indicating very soft water. While the low hardness reduces the risk of scaling in pipes and appliances, B6 may have a slightly more mineral taste, whereas B4 and B8 may be perceived as lighter and more neutral in flavour.

The higher TDS in B6 suggests a greater concentration of dissolved minerals, which may enhance taste and provide essential trace elements like calcium and magnesium, though it could lead to minor scaling in appliances. While low TDS levels, as seen in B8, indicate high purity, they may lack vital minerals, potentially affecting hydration benefits and consumer preference. B6, with its slightly higher TDS, may appeal to those who prefer mineralized water for its enhanced taste and potential health benefits, though it could cause mild scaling in appliances.

5.1.2 Mineral contamination

The assessment to determine the level of minerals contained in the samples of water revealed that calcium content in the sachet water samples ranged from 0.31 mg/L (B4) to 1.25 mg/L (B6), all far below the Ghana Standard of 200 mg/L. This indicates that the sachet water is very soft and lacks significant mineralization. The low calcium levels in the sachet water samples, consistent with previous studies in Ghana, suggest effective purification processes that produce soft water with minimal scaling in appliances. However, this also means the water provides little dietary calcium, which may be a concern for populations relying on drinking water as a mineral source. The sachet water samples had magnesium levels ranging from 0.13 mg/L to 0.38 mg/L, well below the recommended safety limits. This suggests that the water contains very little magnesium, contributing minimally to dietary intake.

The iron level in the sachets of water was between 0.00 mg/L and 0.05 mg/L, all of which were within the permissible limits as stipulated by Ghana Standards and WHO, although iron is an important element in the formation of red blood cells, the small quantities present in the water imply it is iron-free, as it does not stain, support bacteria growth, nor have an unpalatable taste associated with it. Besides, the iron concentration is remarkably low, even when at its highest (0.05 mg/L), which shows that the water treatment processes are thorough, as it is therefore crystal clear, devoid of metallic taste, and never discolored. The chloride levels in the sachets of water were between 9.7 mg/L and 17.7 mg/L, which were below the permissible limits stipulated by Ghana Standards, as well as WHO, of 250 mg/l, making the water quite pure, having little chances of salt uptake, which could cause corrosion of water pipes, thus making it great-tasting.

The sulphate levels in the sachet water samples ranged from 0.00 mg/L to 2.30 mg/L, far below the permissible limits set by both Ghana Standards (250 mg/L). This indicates minimal sulphate contamination, aligning with previous studies that also reported low levels below 5 mg/L. As a result, the sachet water poses no risk of laxative or gastrointestinal effects, making it safe for all consumers. Phosphate levels in the sachet water samples had its lowest concentration of 0.14 mg/L and highest of 0.61 mg/L among the brands assessed. This suggests minimal phosphate content in sachet water sold in Winneba, posing no immediate health risks. The calcium content had an average of 0.5013 mg/L with a standard deviation of 0.30838, showing minimal variation across the sachet water brands. Magnesium levels had a mean of 1.9363 mg/L, with a high standard deviation of 4.87516 and variance of 23.767, indicating substantial variability between brands. Iron content was low with a mean of 0.0138 mg/L and a standard deviation of 0.01996, demonstrating consistency across all samples. Chloride, sulphate, and phosphate concentrations had moderate to low variation, with means of 12.2625 mg/L, 1.1213 mg/L, and 0.3338 mg/L, respectively, and all values remained within safe drinking limits.

5.1.3 Bacteriological quality

It was also noted from the evaluation of the bacteriological quality of the various brands of sachet water that the levels of total coliforms in the sachet water samples varied significantly, with the results from sample B3 and B8 satisfying the WHO and Ghana Standards requirements of zero coliforms. Water samples B1, B2, B4, B5, B6, and B7 exceeded the permissible limit, which implies the possibility of the samples being contaminated during processing or storage. It should be noted that, all the sachet water samples were negative for the presence of *Salmonella species*, thus removing the likelihood of health risk from these bacteria, which aligns with the observations made by other studies noting low levels of *Salmonella* in sachet water. The sachet water samples showed different levels of *Enterobacter spp*. contamination. B6 recorded the highest level of *Enterobacter spp*. at 333 cfu/100 mL, which was above the safety standard. Similarly, *Enterobacter spp*. were found in B1, B8, and B5 in higher amounts, indicating possible contamination. However, none of B2, B3, B4, and B7 showed any *Enterobacter species*, which met WHO and Ghana Standards.

5.1.4 Associated Health Risk

Human health risk is known to be associated with the quality of sachet water if contaminated by physicochemical agents and the bacteriological quality of the water. Such an evaluation in this study found that most of the sachet water brands tested were within the acceptable pH range of 6.5–8.5, as recommended by the WHO, with pH values ranging from 6.89 to 7.24. While none of the samples had an acidic pH, which could lead to heavy metal poisoning, excessive alkalinity above 8.5 could cause digestive and electrolyte issues. Extremely low mineral content in water, such as that in sample B8 with a TDS of 12.57 mg/L, can lead to electrolyte imbalances and increase the risk of dehydration and nutritional deficits.

The microbial contaminants, particularly total coliform and *Enterobacter spp*., posed the biggest risk in the consumption of the sachet waters, as they were the highest in samples B2, B1, B7, and B6. The highest coliform contamination was in sample B1, which went beyond the limits of safety, implying that it is possible it was contaminated during the process or storage. Samples B1, B8, and B5, particularly, were the most contaminated by *Enterobacter spp*., and the highest count was in sample B6, which is a major public health problem. Acute gastroenteritis is caused by *Enterobacter spp*., particularly in people who are most vulnerable, such as infants, the aged, and the *immunocompromised*.

The study found a statistically significant positive relationship between *Enterobacter spp*. and electrical conductivity (0.917, $p = 0.001$), TDS (0.918, $p = 0.001$), and hardness (0.890, $p = 0.003$), indicating that higher mineral content in sachet water increases the likelihood of *Enterobacter spp*. presence. There was also a moderately favourable but non-significant association between pH and *Enterobacter spp*. (0.462, p = 0.249), suggesting pH alone has little effect on bacterial growth. High values in electrical conductivity, TDS, and hardness, which are associated with the presence of *Enterobacter spp*., appear to point towards external contamination factors like industrial discharges, poor filtration practices, and leaching from distribution system equipment. Lack of association of the total coliform count with physicochemical parameters also points towards secondary contamination factors like poor handling and/or exposure to environment-related factors. It is therefore crucial to adhere to safety and hygiene protocols in the procurement and packaging of sachet water.

5.2 Conclusions

It is concluded from the findings that:

1. The sachet water samples showed safe physicochemical properties. All tests for pH, colour, and conductivity fell within WHO and Ghana Standards, ensuring the water's safety and aesthetic quality. The turbidity, hardness, and TDS were within acceptable levels according to WHO and Ghana Standards. In a nutshell, the sachet water samples tested for turbidity, hardness, and TDS were within acceptable limits according to WHO and Ghana standards, hence provided clear and safe water.

2. The low iron levels found within the sachet waters indicate that the filtration processes were effective. Not only is the water clean, devoid of metallic taste, and free from discoloration, but the iron levels are low. The low levels of chlorides found within the sachet waters indicate that the levels of salt contamination are small, leading to minimum corrosiveness of the infrastructure while still maintaining a great taste. The low levels of calcium and magnesium found within the sachet waters

indicate that while the water is soft and free from the effects of minerals, there is a lack of nutritional benefit from these two (calcium and magnesium) essential nutrients found within the nutritive value of the water.

3. Most of the sachet water brands analyzed had a pH within the acceptable range of 6.5–8.5 and showed very low average mineral contents, especially calcium. Even though most sachet water samples analyzed were within safety limits regarding total coliforms, with the absence of E. coli and *Salmonella Spp*. In all samples, a few of the brands exceeded the permissible limits, which shows that potential contamination may be present, especially regarding *Enterobacter spp.*

4. Based on the findings of this study, the sachet water samples analyzed generally pose a low risk to human health, as most physicochemical and microbiological parameters complied with the World Health Organization (WHO) and Ghana Standards. The acceptable pH, colour, conductivity, turbidity, hardness, and total dissolved solids indicate that the water is safe and suitable for consumption. Additionally, the low levels of iron and chlorides suggest effective treatment processes and minimal risks related to taste, corrosion, and metal contamination. However, the consistently low concentrations of essential minerals such as calcium and magnesium imply limited nutritional contribution from the sachet water. Although the majority of samples were free from *E.coli* and *Salmonella spp*., the detection of elevated total coliforms and possible *Enterobacter spp*. contamination in a few brands indicates potential health risks if quality control lapses occur. Overall, while sachet water remains largely safe for consumption, continuous monitoring and enforcement of regulatory standards are necessary to safeguard public health.

5.3 Recommendations

Based on the findings and the conclusion made thereon, the following recommendations are outlined for stakeholder considerations:

Sachet Water Producers

Producers should implement continuous monitoring of physicochemical parameters including turbidity, conductivity, and hardness as well as mineral content, especially for calcium, magnesium, and other essential minerals, to maintain consistency in quality assurance and meet consumer expectations for water with optimal health benefits. Regular maintenance and updates to purification processes should be carried out to address any potential variations that could affect water quality, such as changes in water sources or treatment effectiveness.

Producers should prioritize improving hygiene and disinfection protocols during the packaging, storage, and transportation of sachet water to prevent contamination from bacteria like *Enterobacter spp.* Implementing better sterilization methods, such as advanced filtration systems, can help reduce bacterial contamination and improve the overall safety of the product.

Authorities for Quality assurance (FDA and Municipal Assembly)

Given the microbial risks in sachet water, the FDA should strengthen their monitoring systems to focus not only on physicochemical parameters but also on microbial contamination levels, including regular testing for coliforms and pathogens. Quality assurance authorities should enforce stricter bacteriological testing and monitoring protocols for sachet water producers, ensuring compliance with WHO and Ghana Standards. Regular inspections and audits can help identify any gaps in the water treatment process, ensuring that all producers adhere to the necessary safety and hygiene standards. The Municipal Assembly should launch campaigns to educate consumers highlighting how sachet water can be a source of essential minerals like calcium and magnesium.

5.4 Suggestion for Future Study

It is suggested for future study to delve into evaluating the risk factors and mitigation strategies for bacterial contamination in packaged drinking water vended at Winneba, Ghana.

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APPENDIX A

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
pH level of Water sample	24	6.89	7.24	7.0575	.12903
Electrical Conductivity (µS/cm)	24	23.63	147.87	47.8225	40.99283
Total Disolve Solids (mg/L)	24	12.57	74.10	24.5337	20.30412
Turbidity (NTU)	24	.38	1.33	.6025	.31148
Hardness (mg/L)	24	1.33	4.67	2.0837	1.08156
Colour (Hazen Unit)	24	.00	.00	.0000	.00000
Valid N (listwise)	24				

APPENDIX B

ANOVA on Physicochemical properties

		Sum of Squares	df	Mean Square	F	Sig.
pH level of Water sample	Between Groups	.117	7	.017	.	.
	Within Groups	.000	0	.		
	Total	.117	7			
Electrical Conductivity (µS/cm)	Between Groups	11762.885	7	1680.412	.	.
	Within Groups	.000	0	.		
	Total	11762.885	7			
Total Disolve Solids (mg/L)	Between Groups	2885.801	7	412.257	.	.
	Within Groups	.000	0	.		
	Total	2885.801	7			
Turbidity (NTU)	Between Groups	.679	7	.097	.	.
	Within Groups	.000	0	.		
	Total	.679	7			
Hardness (mg/L)	Between Groups	8.188	7	1.170	.	.
	Within Groups	.000	0	.		
	Total	8.188	7			
Colour (Hazen Unit)	Between Groups	.000	7	.000	.	.
	Within Groups	.000	0	.		
	Total	.000	7			

APPENDIX C

One-way ANOVA on presence of *Enterobacter spp*

Enterobacter spp present in the samples		Sum of Squares	df	Mean Square	F	Sig.
Entero_B1_exp	Between Groups	2816.667	1	2816.667	.333	.667[a]
	Within Groups	8450.000	1	8450.000		
	Total	11266.667	2			
Entero_B2_exp	Between Groups	.000	1	.000	.	.
	Within Groups	.000	1	.000		
	Total	.000	2			
Entero_B3_exp	Between Groups	.000	1	.000	.	.
	Within Groups	.000	1	.000		
	Total	.000	2			
Entero_B4_exp	Between Groups	.000	1	.000	.	.
	Within Groups	.000	1	.000		
	Total	.000	2			
Entero_B5_exp	Between Groups	450.667	1	450.667	.333	.667[a]
	Within Groups	1352.000	1	1352.000		
	Total	1802.667	2			
Entero_B6_exp	Between Groups	155204.167	1	155204.167	.333	.667[a]
	Within Groups	465612.500	1	465612.500		
	Total	620816.667	2			
Entero_B7_exp	Between Groups	.000	1	.000	.	.
	Within Groups	.000	1	.000		
	Total	.000	2			
Entero_B8_exp	Between Groups	12696.000	1	12696.000	.333	.667[a]
	Within Groups	38088.000	1	38088.000		
	Total	50784.000	2			

APPENDIX D

Chloride: Descriptive Statistics

Mineral value (mg

	N	Mean	Std. Deviation	Minimum	Maximum		
						F	Sig.
B1	3	12.6667	8.14453	7.00	22.00		
B2	3	13.3333	4.50925	9.00	18.00		
B3	3	11.3333	5.85947	7.00	18.00		
B4	3	13.6667	12.42310	6.00	28.00		
B5	3	9.6667	6.42910	5.00	17.00		
B6	3	17.6667	3.78594	15.00	22.00		
B7	3	10.6667	9.07377	4.00	21.00		
B8	3	10.0000	9.53939	4.00	21.00		
Total	24	12.3750	7.07606	4.00	28.00	.324	.932

Chloride: ANOVA

Mineral value (mg/L)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	142.958	7	20.423	.324	.932
Within Groups	1008.667	16	63.042		
Total	1151.625	23			

APPENDIX E

Calcium: Descriptive statistics

Mineral value (g/mL)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
B1	2	.4400	.28284	.20000	-2.1012	2.9812	.24	.64
B2	3	.4000	.08000	.04619	.2013	.5987	.32	.48
B3	3	.4267	.04619	.02667	.3119	.5414	.40	.48
B4	3	.3067	.15144	.08743	-.0695	.6829	.20	.48
B5	3	.3733	.04619	.02667	.2586	.4881	.32	.40
B6	3	1.2533	1.00027	.57750	-1.2315	3.7381	.56	2.40
B7	3	.4800	.13856	.08000	.1358	.8242	.32	.56
B8	3	.3200	.00000	.00000	.3200	.3200	.32	.32
Total	23	.5026	.43699	.09112	.3136	.6916	.20	2.40

Calcium: ANOVA

Mineral value (g/mL)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.014	7	.288	1.974	.127
Within Groups	2.187	15	.146		
Total	4.201	22			

APPENDIX F

Magnesium: Descriptive statistics

Mineral value (mg/L)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
B1	3	.1300	.05196	.03000	.0009	.2591	.10	.19
B2	3	.1600	.09849	.05686	-.0847	.4047	.05	.24
B3	3	.2233	.02887	.01667	.1516	.2950	.19	.24
B4	3	.1367	.04726	.02728	.0193	.2541	.10	.19
B5	3	.2567	.02887	.01667	.1850	.3284	.24	.29
B6	3	.3767	.19630	.11333	-.1110	.8643	.15	.49
B7	3	.1967	.08083	.04667	-.0041	.3975	.15	.29
B8	3	.1300	.13856	.08000	-.2142	.4742	.05	.29
Total	24	.2013	.11652	.02378	.1520	.2505	.05	.49

Magnesium: ANOVA

Mineral value (mg/L)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.151	7	.022	2.144	.098
Within Groups	.161	16	.010		
Total	.312	23			

APPENDIX G

Iron: Descriptive statistics

Mineral value (mg/L)								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	3	.0200	.01732	.01000	-.0230	.0630	.01	.04
2	3	.0033	.00577	.00333	-.0110	.0177	.00	.01
3	3	.0067	.01155	.00667	-.0220	.0354	.00	.02
4	3	.0033	.00577	.00333	-.0110	.0177	.00	.01
5	3	.0067	.00577	.00333	-.0077	.0210	.00	.01
6	3	.0367	.04041	.02333	-.0637	.1371	.00	.08
7	3	.0000	.00000	.00000	.0000	.0000	.00	.00
8	3	.0000	.00000	.00000	.0000	.0000	.00	.00
Total	24	.0096	.01829	.00373	.0019	.0173	.00	.08

Iron: ANOVA

Mineral value (mg/L)					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.003	7	.000	1.774	.162
Within Groups	.004	16	.000		
Total	.008	23			

APPENDIX H

Sulphate: Descriptive statistics

Mineral value (mg/L)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	3	.3833	.66395	.38333	-1.2660	2.0327	.00	1.15
2	3	2.1000	3.38083	1.95192	-6.2984	10.4984	.00	6.00
3	3	2.5733	3.85047	2.22307	-6.9918	12.1384	.00	7.00
4	3	.2500	.43301	.25000	-.8257	1.3257	.00	.75
5	3	1.9200	2.69429	1.55555	-4.7730	8.6130	.00	5.00
6	3	.7867	.36950	.21333	-.1312	1.7046	.36	1.00
7	3	1.5500	2.14651	1.23929	-3.7822	6.8822	.00	4.00
8	3	1.0867	1.66209	.95961	-3.0422	5.2155	.00	3.00
Total	24	1.3312	2.06584	.42169	.4589	2.2036	.00	7.00

Sulphate: ANOVA

Mineral value (mg/L)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	14.857	7	2.122	.408	.884
Within Groups	83.300	16	5.206		
Total	98.157	23			

APPENDIX I

Phosphate: Descriptive statistics

Mineral value (mg/L)								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	3	.3767	.37421	.21605	-.5529	1.3063	.09	.80
2	3	.1133	.10263	.05925	-.1416	.3683	.00	.20
3	3	.2067	.16773	.09684	-.2100	.6233	.10	.40
4	3	.1733	.06429	.03712	.0136	.3330	.10	.22
5	3	.1767	.19655	.11348	-.3116	.6649	.03	.40
6	3	.1900	.09644	.05568	-.0496	.4296	.12	.30
7	3	.1800	.18000	.10392	-.2671	.6271	.00	.36
8	3	.3233	.41645	.24044	-.7112	1.3579	.03	.80
Total	24	.2175	.21193	.04326	.1280	.3070	.00	.80

Phosphate: ANOVA					
Mineral value (mg/L)					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.160	7	.023	.418	.877
Within Groups	.873	16	.055		
Total	1.033	23			