

**KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
COLLEGE OF ENGINEERING
DEPARTMENT OF MATERIALS ENGINEERING**

**WATER QUALITY DETERIORATION IN PIPED WATER AND ITS
EFFECT ON USAGE AND CUSTOMERS' PERCEPTION: CASE STUDY OF
ADUM- KUMASI, GHANA**

BY

UMAR MOHAMMED

(BSc. MATERIALS ENGINEERING)

**Thesis submitted to the College of Engineering in partial fulfilment of the
requirement for the award of
MSc. degree in Environmental Resources Management**

APRIL, 2012

DECLARATION

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

UMAR MOHAMMED
(PG 3661509)	Signature	Date

Certified by:

Dr. A. A. ADJAOTTOR.
(Supervisor)	Signature	Date

Dr. R. A. Buamah.
(Supervisor)	Signature	Date

Certified by:

Prof. S. Kwofie
(Head of Department)	Signature	Date

ABSTRACT

Assessment of drinking water quality is important for sustainable development. Safe water is the door way to health and health is the pre-requisite for progress, social equity and human dignity. A study on households' drinking water quality in Western Accra of Ghana from the Weija head-works revealed that the supplied water at some locations did not meet the potable water quality standard. This being the case, the question then arises as to whether it is an isolated case, or that the situation may be recurring in other parts of the country.

The main goal of this study was to determine the water quality deterioration in piped water and its effect on water usage and customers' perception at Adum in the Kumasi Metropolis of the Republic of Ghana. The specific objective of the study were to determine the quality of the treated water at Barekese headworks, to determine the quality of water from the household taps in the selected study area and to investigate customer perception on the quality of water delivered and its effect on usage.

Fifty (50) water samples were taken from the Barekese Headworks, Suame reservoir and households at Adum. The samples were analyzed for the following selected physicochemical and bacteriological parameters: pH, ammonia, residual chlorine, electrical conductivity, total dissolved solids, alkalinity, calcium hardness, magnesium hardness, total hardness, magnesium, calcium, total iron, manganese, nitrate-nitrogen, turbidity, temperature, *Escherichia coli*, *salmonella* and faecal coliform. Consumer perception survey was used to examine the consumers' perception of the water quality and how it affects their usage of the supplied water.

The study revealed that the mean concentrations of all of the investigated physicochemical parameters in the drinking water samples were within the

permissible limits of the World Health Organization (WHO)/Ghana Standard Authority (GSA) drinking water quality guidelines. More than half of the water samples collected from the Barekese Headworks, Suame reservoir and households indicated minimal contamination by *E.coli* and other coliform especially. Many (86%) customers did not have problems with the taste of the water whilst 84% of the customers had no problem with the smell of the water supplied. Eighty (80%) of the customers were satisfied with the colour of the water. The major complaint (50%) was with the sediment content of the water which needs to be looked at. All the consumers complained about the quality of the water supplied immediately after interruption. Customers' perception of the water taste, smell and colour affected their choice of the water for drinking. The consumers' usage of the water for drinking was independent of the sediment content. Usage of the water for cooking among the respondents was not influenced by their perception about the aesthetic appearance of the water.

TABLE OF CONTENTS

DECLARATION.....	II
ABSTRACT.....	III
TABLE OF CONTENTS	V
LIST OF FIGURES	IX
LIST OF TABLES	X
GLOSSARY OF ABBREVIATIONS	XI
ACKNOWLEDGEMENTS	XII
CHAPTER ONE	1
1 INTRODUCTION.....	1
1.1 BACKGROUND.....	1
1.2 PROBLEM STATEMENT	4
1.3 JUSTIFICATION OF STUDY	5
1.4 STUDY OBJECTIVES	7
1.5 STRUCTURE OF THE THESIS	7
CHAPTER TWO	8
2. INTRODUCTION	8
2.1 IMPORTANCE OF WATER.....	8
2.2 DESCRIPTION OF WATER SUPPLY SYSTEM.....	9
2.3 WATER SUPPLY IN AFRICA.....	10
2.4 WATER SUPPLY IN GHANA	12
2.5 INDICATORS OF WATER QUALITY	14
2.5.1 Turbidity	14

2.5.2	Total Dissolved Solids (TDS).....	15
2.5.3	Temperature	15
2.5.4	Alkalinity	16
2.5.5	Hardness.....	16
2.5.6	pH.....	17
2.5.7	Colour	17
2.5.8	Conductivity.....	18
2.5.9	Iron.....	18
2.5.10	Manganese	19
2.5.11	Nitrate and Nitrite	19
2.5.12	Faecal Coliform	20
2.6	DISTRIBUTION SYSTEM PIPES	21
2.7	TRENDS RELEVANT TO THE DETERIORATION OF WATER IN DISTRIBUTION SYSTEMS	21
2.7.1	Biofilm growth.....	21
2.7.2	Intermittent Water Supply.....	24
2.7.3	Main Breaks, Repairs and Installation.....	25
2.7.4	Disinfection and Disinfection By-Products (DBPs)	27
2.7.5	Corrosion and Scale Formation	28
2.7.6	Sediment build-up.....	30
2.7.7	Finished Water Storage.....	31
CHAPTER THREE		35
3	STUDY AREA, MATERIALS AND METHODS	35
3.1	BACKGROUND OF THE STUDY AREA	35

3.2	DESK STUDY	38
3.3	LOCATION AND COLLECTION OF WATER SAMPLES.....	38
3.4	CUSTOMER PERCEPTION SURVEY	43
3.4.1	Purpose of survey.....	43
3.4.2	Design of survey instrument	43
3.4.3	Sampling	43
3.4.4	Manager’s Survey	44
3.4.5	Analysis of questionnaires	44
3.5	FIELD ANALYSIS OF WATER SAMPLES	44
3.5.1	Temperature, pH, TDS and EC.....	44
3.5.2	Turbidity and Free Residual Chlorine (F Cl).....	45
3.6	LABORATORY ANALYSIS	47
3.6.1	Total Hardness	47
3.6.2	Calcium Hardness	47
3.6.3	Alkalinity	48
3.6.4	E.coli, Salmonella and Faecal Coliforms.....	48
3.7	ANALYSIS FOR HEAVY METALS.....	49
3.8	SPECTROPHOTOMETRIC ANALYSIS.....	50
3.8.1	Iron.....	50
3.8.2	Nitrate-nitrogen.....	50
3.8.3	Nitrogen-ammonia	51
CHAPTER FOUR.....		53
4	RESULTS AND DISCUSSION	53
4.1	LABORATORY AND FIELD TEST.....	53

4.1.1	Turbidity	53
4.1.2	Total Dissolved Solids (TDS).....	54
4.1.3	Temperature	56
4.1.4	Hardness.....	57
4.1.5	Alkalinity	57
4.1.6	pH.....	58
4.1.7	Electrical Conductivity (EC).....	59
4.1.10	Nitrate-Nitrogen (NO ₃ -N) and Ammonia	63
4.1.11	Microbial content and Residual Chlorine level	64
4.2	CUSTOMER PERCEPTION SURVEY	66
4.2.1	Perception on Physical properties of tap water and water usage.....	66
4.2.2	Handling of Leakages	71
4.2.3	Intermittent water supply	72
CHAPTER FIVE		73
5	CONCLUSIONS AND RECOMMENDATIONS.....	73
5.1	CONCLUSIONS.....	73
5.2	RECOMMENDATIONS.....	74
REFERENCES.....		76
APPENDICES.....		85
APPENDIX 1 – QUESTIONNAIRE		86
APPENDIX 2 – NULL HYPOTHESIS		88

LIST OF FIGURES

Figure 2.1: Biofilm growth inside the pipe (Source: USEPA, 2008)	23
Figure 2.2: Corrosion tubercles in an old cast iron main.....	29
Figure 3.1A: Map showing the GWCL eight (8) water distribution districts.....	36
Figure 3.1B: Map of central district indicating study area (Adum).....	36
Figure 3.2: Map of GUWL distribution network showing sampling locations	41
Figure 4.1: Turbidity of the water samples	54
Figure 4.2: Occurrence of TDS in the water samples	55
Figure 4.3 Temperature level of the water samples	56
Figure 4.4: Mean Mg, Ca and total hardness of the water samples	57
Figure 4.5: Occurrence of total alkalinity in water samples	58
Figure 4.6: Level of pH in the water samples	59
Figure 4.7: Electrical conductivity of the water samples.....	60
Figure 4.8: Level of colour in the water samples.....	61
Figure 4.9: Total iron and manganese concentration of the water samples.....	62
Figure 4.10: Concentration of Ca and Mg in the water samples	63
Figure 4.11: Occurrence of NO ₃ -N in water samples	64
Figure 4.12: Occurrence of <i>E.coli</i> , <i>salmonella</i> and faecal coliform in water samples	65
Figure 4.13: Occurrence of residual chlorine in water samples.....	66
Figure 4.14: Consumer Perception on Colour, Taste and Smell of Water	67
Figure 4.15: Sediment Content of Water	67
Figure 4.16: water usage	68
Figure 4.17: drinking of alternate water source	68
Figure 4.18: Handling of leakages	72
Figure 4.19: Intermittent water supply.....	72

LIST OF TABLES

Table 3.1: GWCL customer population distribution	38
Table 3.2: Summary of sampling schedule.....	40
Table 3.3: Maximum delay between sampling and analysis and preservation method	42
Table 3.4: Method of sample analysis	45
Tab 4.1: Quality classification of drinking water (WHO, 2006).....	55
Table 4.2: Satisfaction with physical appearance of water and usage for drinking.....	71
Table 4.3: Non satisfaction with physical appearance of water and usage for drinking	71

GLOSSARY OF ABBREVIATIONS

AWWA:	American Water Works Association
CWSA:	Community Water and Sanitation Agency
DBPs:	Disinfection and Disinfection By-Products
EDTA:	Ethylenediaminetetra-acetic acid
EPA:	Environmental Protection Agency
GUWL:	Ghana Urban Water Limited
GWSC:	Ghana Water and Sewage Corporation
KMA:	Kumasi Metropolitan Assembly
KWSS:	Kumasi Water Supply System
PURC:	Public Utility Regulatory Commission
THMs:	Trihalomethanes
UKWIR:	United Kingdom Water Industry Research
UNCED:	United Nations Conference on Environment and Development
UNESCO:	United Nations Education and Culture Organisation
UNDP:	United Nations Development Programme
UNICEF:	United Nations Children's Fund
WHO:	World Health Organization
WRC:	Water Resource Commission
NTU:	Nephelometric turbidity units

ACKNOWLEDGEMENTS

I give glory and thanks to Allahu (subhaanahu wa ta'ala) for the strength to pursue this research study. My appreciation goes to my supervisors, Dr. R. Buamah and Dr. A. A. Adjaottor, who graciously took the time to provide critical inputs that greatly improved the quality of this work. To them I say keep up with your good work and may Allah shower His blessings on you.

To the entire lecturers and staff of the Environmental Resources Management Department of KNUST, where this study was carried out, I am extremely grateful for their magnificent tuition and guidance. The contributions and efforts of Mr. Samuel Gikunoo and Gloria (GUWL- Ashanti regional head office, Regional GIS office), Mr. Kinsley of the Water Resources and Environmental Sanitation Project (WRESP) laboratory, Mrs. Lydia Gyamfi (Laboratory Technician, GUWL Headworks-Barekese) and Martins need to be complemented.

This list of worthy personalities will be incomplete without the mention of my Kumasi Landlord (Mr Baba), his caring Wife (Amalya) and brother (Mr Sule) for their physical and psychological support.

My wonderful family, especially my mum, Hajia Hawa Adam have been of enormous help to me and I owe them a great debt of gratitude. Aside of my supportive family, I am also grateful to my friends, Muheeb, Husein, Mallam Abubakr, Haq, Basit and those I may have forgotten to thank. I say may Allah reward you. It is your encouragements that has brought me this far.

CHAPTER ONE

1 INTRODUCTION

1.1 Background

“Water,” said the eminent Greek philosopher Pinder, “is the best of all things”. Water has been considered throughout history as a natural resource critical for development (Biswas, 1997). Water is one of the vital components of the physical environment. The quality of drinking water is closely associated with human health, and providing safe drinking water is one of the important public health priorities. It is estimated that 80 per cent of all diseases and over one third of deaths in developing countries are caused by the consumption of contaminated water, and on an average as much as one tenth of each person's productive time is sacrificed to water-related diseases (UNCED, 1992).

The relevance of water as a resource to improve the social well-being of a people and for national development cannot be over-emphasised. That is the reason why the quality and quantity of water supplied to a community is critical in determining their health status, standard of living and level of development (Falkenmark *et al*, 1990). Indeed, the inclusion of water supply, sanitation and hygiene among the Millennium Development Goals (MDGs) indicates that the United Nations has endorsed water quality and its availability in communities as a tool for development. The Millennium Development Goals represent the world’s agreed targets for addressing poverty in its many dimensions. Lack of access to safe drinking water and basic sanitation is one dimension affecting billions of people around the world (Conant, 2005). Access to adequate, safe water is recognized as a human right in many international laws and agreements, for example, the United Nations Charter and several others. Access to

improved water and sanitation is important because it is the foundation of healthy communities, and results in significant health, economic, and social gains (Montgomery *et al.*, 2009).

The per capita demand for water in most countries is steadily increasing as more people achieve higher standards of living and as the lifestyles are changing steadily. For example, in an industrialized nation like Japan, per capita demand for water doubled during the period 1965 to 1991. The situation is more critical for developing countries, where the rates of population growth are the highest (Biswas, 1997).

A significant measure to improve public health, spur economic development, and reduce poverty is universal access to and use of clean water and sanitation services. A legacy of insufficient and unsustainable water and sanitation service delivery means that 884 million individuals still lack access to improved drinking water, and 2.5 billion individuals lack access to improved sanitation (WHO/UNICEF, 2008). Nearly 10% of the total burden of disease worldwide is attributed to unsafe water, poor sanitation, and hygiene, and the associated diseases claim 3.6 million lives annually (Pruss-Ustun *et al.*, 2008). Providing reliable piped-in water must remain a priority, given its high return not only in health gains but also in economic productivity and overall human well-being (Hutton & Haller, 2004).

The Ghana Urban Water Limited (GUWL) is responsible for the provision, installation, distribution and management of urban water supply in Ghana. The Kumasi Water Supply System (KWSS), under the supervision of the GUWL is involved in water abstraction from the Barekese and Owabi headworks, its purification and subsequent distribution to the metropolis in Kumasi.

Potable water utilities often face challenges especially in the urban areas due to increased migration of rural people and increased economic growth as well. Kumasi, the commercial capital of the Ashanti Region, is one of the densely populated urban areas in Ghana which has been suffering from inadequate supply of drinking water often accompanied with water quality problems too.

A drinking water distribution system is a complex net-work of pipes, tanks and reservoirs that delivers finished water to consumers. Collectively, water distribution system infrastructure consists of a variety of equipment such as pumps, pipes, tanks, valves, hydrants and meters, that are built to deliver water from treatment plants to the customer. A drinking water system's water quality may be acceptable when the water just leaves a treatment plant. However, a variety of physical, chemical and biological transformations can occur once the water travels through a distribution system (Rodriguez *et al.*, 1994; Powell *et al.*, 2000; Lahlou, 2002). Deteriorating water treatment facilities and distribution systems can pose a significant public health threat. Microorganisms can attach to pipe surfaces, producing a complex microbiological environment known as "biofilm." Contaminants may infiltrate a distribution system during pipe breaks or through finished water storage facilities. Some of these undesirable water quality changes result in taste and odour problems (USEPA, 2008). In the United States of America, 11-18% (1920-1990) and 22% (1991-1996) of reported outbreaks of waterborne disease were attributable to contamination of the distribution system and storage facilities respectively (Blackburn *et al.*, 2004; Craun and Calderon, 1999; Craun, 1986) whereas in the United Kingdom 36% (1911-1995) of reported waterborne disease outbreaks in public water supplies were related to the distribution system (Hunter, 1997).

It is essential to protect the customer against both aesthetic and public health threats that may result due to undesirable water quality changes in the distribution system. The quality of water from treatment plant that is channelled to the consumer via distribution systems is liable to pollution (Lahlou, 2002) and the effects of polluted water on health makes it necessary for it to be tested to ascertain its quality (physical, chemical, and biological) to meet both international and local standards.

1.2 Problem statement

A study on households' drinking water quality in Western Accra of Ghana from the Weija head-works by Cobbina *et al.* (2009) revealed that the supplied water at some locations did not meet the potable water quality standard. This being the case, the question then arises as to whether it is an isolated case, or that the situation may be replicated in other parts of the country. What is the quality of treated water at the Barekese headworks? Do certain parts of Kumasi, in this case Adum have any shortfalls in terms of the quality of potable water they receive from Barekese? What are the intervening factors responsible for any undesirable change in the quality of water available at the households in Adum. This study seeks to find answers to the above problems by monitoring the changes in water quality as it travels through the distribution network. The study also seeks to provide information on customers' perception of the quality of water in their taps and how this perception affects their usage of tap water.

Although, a drinking water systems' water quality may be acceptable when the water just leaves a treatment plant, it may deteriorate in the course of distribution as a result of:

- 1) Chemical and biological reactions taking place in the water during distribution.
- 2) Reactions between the water and distribution system materials.
- 3) Contamination from external sources that occurs because of main breaks, leaks coupled with hydraulic transients.
- 4) Improperly maintained storage facilities etc.

1.3 Justification of study

The World Health Organization has repeatedly insisted that the single major factor adversely influencing the general health and life expectancy of a population in many developing countries is ready access to clean drinking water (Nash and McCall, 1995). Many common and widespread health risks have been found to be associated with drinking water in developing countries (Suthar, 2008). Unsafe water, poor sanitation and hygiene have been reported to rank third among the 20 leading risk factors for health burden in developing countries (WHO, 2003).

In the past few decades, public concern over the quality of drinking water has grown considerably. These concerns have arisen as a result of increased awareness about environmental pollution and episodes of waterborne disease outbreaks (Anadu and Harding, 2000). The tragedy that struck Walkerton (Canada), where some people died of *Escherichia coli* contamination in the city's water distribution system in May 2000, is a sad but revealing example of the current situation. This new context is reflected in reports that an increasing proportion of residents are choosing some sort of alternative to tap water (Auslander and Langlois, 1993; Larson and Gnedenko, 1999; Anadu and Harding, 2000). In the Quebec City region, for example, Levallois *et al.* (1999) reported that the rejection of tap water is increasing and bottled water is being used

frequently, often in alternation with tap water. Past studies have shown that people reject tap water mainly because of concerns about health risks (Auslander and Langlois, 1993; Anadu and Harding, 2000) or for organoleptic reasons (i.e. colour, odour and taste) (Levallois *et al.*,1999).

Because the aesthetic quality of drinking water is usually the only basis the average consumer has in judging water quality, it seems reasonable to expect that many of those consumers will link an aesthetic problem (an unpleasant odour or taste, for example) to a potential health risk (Jardine *et al.*, 1999). By the same token, drinking water that does not have a noticeable taste, odour or visible colour may be considered by the consumer to be safe, when it actually contains contaminants with potentially adverse health effects. In addition, microbiological contamination and high concentrations of trace organic compounds are not necessarily associated with degradation in the aesthetics of drinking water (Jardine *et al.*, 1999).

Water quality is a key aspect of urban water supply, which may influence community attitudes thereby potentially affecting the sustainability of water supply systems. Perceived poor water quality, influences the use of water thus creating potentials of health risks through the development of unsafe alternative sources. However, every water utility aims to provide drinking water that presents no risks to public health and is, at the same time, aesthetically acceptable. Safe drinking water is generally obtained by complying with specific water quality standards established by governments.

1.4 Study objectives

The goal of this study is to assess water quality deterioration in piped water and its effect on water usage and customers' perception in the Kumasi metropolis using Adum as case study.

The specific objectives are:

- To determine the quality of the treated water at Barekese headworks.
- To determine the quality of water from the household taps in the selected study area.
- To investigate customer perception on the quality of water delivered and its effect on usage.

1.5 Structure of the thesis

This thesis was organized into five main chapters. This chapter has provided background information of the study and presented the study objectives and research justification. A review and discussion of various literature relevant to this research is presented in chapter two. A description of the study area and methodology can be found in chapter three while the derived study results, analysis of these acquired results, and the discussion of the obtained results in relation to existing literature is presented in chapter four. The conclusions and recommendations of the research are presented in chapter five.

CHAPTER TWO

2. INTRODUCTION

Fresh water is a renewable resource that is in continuous movement at the earth's surface (e.g., rivers, streams, and oceans), below the ground in aquifers and in the atmosphere. The natural movement of water is powered by the sun and the earth's gravity. This natural continuous movement of water is called the hydrologic cycle or the "water cycle." In this cycle, water precipitates as rain and falls onto surface storage areas such as lakes, rivers, streams, and oceans. The water on the land and these surface storage areas infiltrates and recharges underground sources called aquifers. Additionally, the water from the surface sources and plants evaporates to form rain-bearing clouds.

Aquifers (ground water) and rivers (surface water) are the main sources of water for most utilities. If the amount (or concentration) of the contaminant material present in the source water supply exceeds drinking water standards, water utilities are required to treat the source water to reduce (or eliminate) the contaminant material to the required standard levels prior to distributing the water to their customers (USEPA, 2008).

2.1 Importance of water

Water is the most important liquid found on earth and the most familiar to man. It is vital for sustaining all life and for economic and social development, including energy production, agriculture, industry and domestic water supplies. Water is considered an economically vital resource and should be used efficiently, equitably and soundly (UNESCO, 1997). Perhaps the most unique characteristic of water is that it occurs on

earth as solid, liquid and gas within the range of climatic condition commonly encountered. Fresh water the most precious of our planets natural resources is a basic ingredient for supporting all life, therefore its resources must be characterized as finite and irreplaceable although availability of fresh water varies widely with geographic location (James and Lamp, 1985).

WHO (1993) stated that water sources must be protected from contamination by human and animal waste. It is better to protect water from contamination than to treat it after it has been contaminated to ensure that the quality of the water is satisfactory for human consumption.

2.2 Description of water supply system

A drinking water supply system usually comprises a source of water, transmission or transportation of the potable water to community, a network of pipes and appurtenances (valves, hydrants, meters, reservoirs) known as the distribution systems that convey potable water to the consumers in a utility's service area in the required quantity at a satisfactory pressure. The water source is either from a well, or from surface water sources based on conventional treatment methods. The water transmission system is made up of large diameter pipes that convey water from the headworks or treatment works to the community for distribution. The distribution network consists of small to medium sized pipes usually laid along the sides of the streets to allow households to tap using their service lines. The engineering aspects (hydraulic and engineering design) of water supply aim at the following:

- Water production of acceptable quantity and quality to meet the population.
- Adequate pressures, velocity and acceptable head loss within the network.

- Engineering design to ensure that the potable water is transported efficiently to the community by selected appropriate pipe sizes (diameters) and appropriate pipe materials.
- Location and design of storage facilities to ensure that there will be adequate water supply during emergency situation break pressure tank in some case depending on the topography.
- Reliable distribution system that ensures good quality of service. Criteria usually include adequate pressures, water quality and reliability of the services.

The exact nature of the water supply system may vary depending on a number of factors such as topography, availability of water resource and its quality. The nature of the water supply system gives rise to peculiar characteristics, which influence how the water system and the sector is organized (Nyarko, 2007).

2.3 Water supply in Africa

Access to safe water supply is a universal need and essential for human development (AfDB, 1999). Yet, nearly 20% of the world's population does not have ready access to drinking water (Suleymanova, 2002). The large majority of those affected are in developing countries, and the United Nations has identified water use as a priority for international aid. Rapid urbanization throughout the developing world has substantially increased the demand for urban water supply and in most countries the supply of services has not kept pace with this increasing demand. Equitable access to clean water and sanitation can improve livelihoods and reduce poverty. According to the United Nations Development Programme (UNDP) many poor people in

developing countries particularly in Africa pay higher prices for water than residents of cities in advanced countries. In cities like Accra, one cubic meter of water may cost as much as three times more than in cities such as New York (www.undp.org).

In Africa, the economic damage done by deficiencies in water supply and sanitation amount to \$28 billion per year which is more than the amount the continent received as development aid in 2003. If, from now on, enough was invested for Africa to reach the goal of halving the number of people without access to clean water by 2015, the annual damage would drop to around \$13 billion, according to the Human Development Report. Its key message is that unfair distribution rather than unavailability of water resources is the main reason for current grievances (www.undp.org).

The development of Africa's water resources has become one of the key objectives of the Bank's development efforts on the continent. African annual renewable water resources, which are estimated at about 5,400 billion m³ per year, are considered to be abundant. These water resources are characterized by extreme temporal and spatial variability with over 60 shared water basins dominating the landscape. However, the exploitation of water resources is low with only about 3 percent of the total amount used under managed condition. Africa is therefore faced with the major challenge of achieving significant development of its water resources to ensure sustained economic growth and social wellbeing (www.afdb.org).

The social cost of Africa's poor exploitation of its water resources is well documented. Currently, about 300 million people in Africa do not have access to safe water and about 313 million have no access to sanitation. Most of Africa's population

lives in rural areas (62 percent) and yet access is lowest in the rural areas, at about 47 percent for water and 45 percent for sanitation (www.who.org).

2.4 Water supply in Ghana

Ghana's water resources can be grouped into surface and groundwater sources. Surface water constitutes the dominant source used in the supply of potable drinking. There are three major rivers that make up the available surface water. These are Volta rivers and Oti river which drains about 70% of the total area of Ghana, the south western rivers (Bia, Tano, Ankobra, Pra) which covers 22% of land area of Ghana, and the Coastal rivers (Tordzie/Aka, Densu, Ayensu, Ochi-Nakwa and Ochi-Amissah) which covers 8% of the total area of Ghana.

The development of public water supply in Ghana began in 1928 in Cape Coast. Between 1928 and 1965, water supply delivery was under the Public Works Department. Public water supply started with the Hydraulics Department (HD) of the Public Works Department (PWD), which was responsible for urban and rural water supply. In 1948, a Rural Water Department (RWD) was formed to take responsibility for water supply in rural areas. After independence in 1957, the water sector was set up as a Water Supply Division (WSD) under the ministry of Works and Housing with responsibilities for both urban and rural water supplies.

A severe water shortage in 1959 prompted the Government of Ghana (GOG) to appeal to the World Health Organisation (WHO) to assess the water supply situation in Ghana. The outcome led to the creation of Ghana Water and Sewerage Corporation (GWSC) from the Water Supply Division (WSD). The Ghana Water and Sewerage Corporation (GWSC) was established in 1965 under Act 310, for the provision, distribution and conservation of both urban and rural supply of water in Ghana for

public, domestic and industrial purposes, as well as the establishment, operation and control of sewerage systems. Over the past two decades, a number of reforms in the water sector were initiated with the aim of improving management and coordination of the country's water resources and systems. As part of the water sector reform, three new regulatory bodies were established; the Environmental Protection Agency (EPA), Public Utilities Regulatory Commission (PURC) and Water Resources Commission (WRC). Those agencies were formed to be in charge of environmental, tariff and overall resource management issues respectively. On the 1st of July 1999 GWSC was converted into a 100% state owned Limited Liability. Ghana Water and Sewerage Corporation in pursuant to the statutory Corporation Act, 1993 (Act 461) as amended, was converted into a Limited Liability Company under the new name Ghana Water Company Limited (GWCL).

There are two distinct management arrangements for the supply of water in Ghana, a separation into urban and rural water supply. Ghana Water Company Limited (GWCL), formerly Ghana Water and Sewerage Company (GWSC) was responsible for water supply and has about 80 systems serving a total population of about eight million. Urban water coverage is estimated at 59% and is expected to reach 85% by 2015 (GPRS, 2002-2004) in line with the Millennium Development Goals. Many urban areas face shortfalls in water supply. The GWCL faces considerable challenges including over-aged facilities, a rapid growing population, low tariffs that affected its ability to generate sufficient revenue for rehabilitation and expansion, and high levels of unaccounted for water (about 52%). Water supply in the rural areas is currently under the Community Water and Sanitation Agency (CWSA). The principal source of rural water is groundwater in the form of boreholes and surface water such as rivers and streams. Water coverage in the rural areas is estimated to be 49% (WHO and

UNICEF, 2000). About 4 out of 10 Ghanaian households within the piped areas of the urban sectors are GWCL customers. The majority of households in piped areas do not have primary access to piped water, most especially the urban poor despite a high preference for GWCL services. The water sources on which the non-piped areas rely on are more expensive than the piped water (National Water Policy, 2005).

Poor urban development and population growth is the major cause of this situation in the country. As a result, most homes in the urban cities use water tanks to store water since the taps are not reliable. This condition has led to the evolution of various tanker water supply services. These tankers distribute water to both private and public institutions. Their activities are coordinated by the Tanker Associations and the rate for the private water tankers is determined by the Public Utility Regulatory Commission together with GWCL (www.arch.columbia.edu./studio/spring2003/UP/Accra).

2.5 Indicators of water quality

In measuring the quality of any water, the characteristics of the water must be clearly stated. For drinking water, it may include the following parameters: colour, turbidity, temperature, conductivity, total hardness, concentration of organic and inorganic compounds (Ray, 1995; Borchardt and Walton, 1971).

2.5.1 Turbidity

Turbidity in water is caused by the presence of suspended matter, such as clay, silt, fine particles of organic and inorganic matter, plankton and other microscopic organisms. The standard measure of turbidity is an expression of the optical property of a water sample which causes light to be scattered and absorbed rather than

transmitted in straight lines through the sample. As the number of particles increases, more light is scattered, and higher turbidity readings are obtained (Shelton and Scibilia, 2005). High turbidity levels can reduce the efficiency of disinfection by creating a disinfection demand. The particles may also provide absorption sites for toxic substances in the water. It may protect pathogens from disinfection by absorbing or encasing them, and may interfere with total coliform analysis (USEPA, 1995). The measuring instrument is called a turbidimeter, and the readings are expressed as nephelometric turbidity units (NTU) or turbidity units (Shelton and Scibilia, 2005).

2.5.2 Total Dissolved Solids (TDS)

The palatability of water with a TDS level of less than 600 mg/L is commonly considered to be good (WHO, 2006); drinking-water becomes appreciably and increasingly unpalatable at TDS levels greater than about 1000 mg/L. TDS is made up of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulphates) and organic matter that are dissolved in water. The presence of high levels of TDS may also be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances. No health-based guideline value for TDS has been proposed. (WHO, 2006 and Hach, 2000).

2.5.3 Temperature

Depending on whether temperature is high or low, it may affect other parameters including conductivity and dissolved minerals. Cool water is generally more palatable than warm water. Temperature affects the reaction rates and solubility levels of chemicals present in water. High water temperature enhances the growth of microorganisms and may increase taste, odour, colour and corrosion problems. It is determined using a Temperature meter (Schindler, 1990; Hach, 2000; WHO, 2006).

2.5.4 Alkalinity

Alkalinity is the ability of water to resist a change in pH when acid is added; it relates to the pH buffering capacity of the water. Almost all natural waters have some alkalinity and it is nature's means of keeping pH stable. Alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. The presences of buffering compounds help neutralize acids as they are added to water. These buffering compounds are primarily the bases; bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), and occasionally hydroxide, borate, silicates, phosphates, ammonium and sulphides. Water with low alkalinity is very susceptible to changes in pH (www.idph.state.il.us/envhealth/pdf/Drinkingwater.pdf).

2.5.5 Hardness

Hardness caused by calcium and magnesium is usually indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning. The taste threshold for calcium ion is in the range of 100–300 mg/L, depending on the associated anion, and the taste threshold for magnesium is probably lower than that for calcium. In some instances, consumers tolerate water hardness in excess of 500 mg/L. Depending on pH and alkalinity, water with hardness above approximately 200 mg/L may cause scale deposition in the treatment works, distribution system and pipe work and tanks within buildings. It will also result in excessive soap consumption and subsequent “scum” formation. On heating, hard waters form deposits of calcium carbonate scale. Soft water, with a hardness of less than 100 mg/L, may, on the other hand, have a low buffering capacity and so be more corrosive for water pipes. No health-based guideline value is proposed for hardness in drinking-water (WHO, 2006). Water

hardness is determined by titration with EDTA (Ethylenediaminetetra-acetic acid) (AWWA, 1999 and Kruis, 2007).

2.5.6 pH

Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters. pH is a numerical expression of the hydrogen ion concentration indicating the degree to which a water is acidic or alkaline. The pH of the water entering the distribution system must be controlled to minimize the corrosion of water mains and pipes in household water systems. Low pH levels are objectionable because of the corrosive effect on metal pipes and fixtures, causing leaching of lead from solder in pipes in older homes, lead from brass plumbing fixtures, and the metallic taste frequently associated with low pH water. Additionally, dissolved iron in low pH water stains porcelain plumbing fixtures. High pH levels are undesirable as well since they may impart a bitter taste to the water. Furthermore, the high degree of mineralization associated with alkaline waters will result in the encrustation of water pipes and water-using appliances. The combination of high alkalinity and calcium with low pH levels may be less corrosive than water with a combination of high pH, low alkalinity, and calcium content. High pH levels also depress the effectiveness of disinfection by chlorination, thereby requiring the use of additional chlorine or longer contact times. A range of 6.5 - 8.5 was determined as that pH which would achieve the maximum environmental and aesthetic benefits (WHO, 2006; Shelton and Scibilia, 2005).

2.5.7 Colour

Drinking-water should ideally have no visible colour. Colour may be indicative of large quantities of organic chemicals, inadequate treatment, high disinfectant demand,

and the potential for production of excess amounts of disinfectants' by-products such as trihalomethanes. Natural colour may be caused by decaying leaves, plants, and soil organic matter. Colour is also strongly influenced by the presence of iron and other metals, either as natural impurities or as corrosion products. The source of colour in a drinking-water supply should be investigated, particularly if a substantial change has taken place. Most people can detect colours above 15 true colour units (TCU) in a glass of water. Levels of colour below 15 TCU are usually acceptable to consumers, but acceptability may vary. While colour itself is not usually objectionable from the standpoint of health, its presence is aesthetically objectionable. High colour could also indicate a high propensity to produce by-products from disinfection processes. No health-based guideline value is proposed for colour in drinking-water (WHO, 2006; Shelton and Scibilia, 2005). Colour is determined using a spectrophotometer (Hach, 2000).

2.5.8 Conductivity

The ability of water to conduct electric current is a measure of its conductivity. Conductivity is directly related to the total dissolved salt content of the water. This is so because the salts dissolve into positive and negative ions and can conduct electric current proportional to their concentration. It is reported in micro Siemens per centimetre ($\mu\text{S}/\text{cm}$) using a conductivity meter (Hach, 2000).

2.5.9 Iron

Iron promotes the growth of “iron bacteria,” which derive their energy from the oxidation of ferrous iron to ferric iron and in the process deposit a slimy coating on pipes. At levels above 0.3 mg/L, iron stains laundry and plumbing fixtures. Iron is an essential nutrient, but some people who drink water with iron levels well above the

recommended upper limit could develop deposits of iron in a number of organs of the body (haemochromatosis) (Shelton and Scibilia, 2005). There is usually no noticeable taste at iron concentrations below 0.3 mg/L, although turbidity and colour may develop. The provisional guideline value of 0.3 mg/L represents a reasonable compromise, as adverse aesthetic effects are minimized at this level.

2.5.10 Manganese

Excess manganese produces a brownish colour in laundered goods and impairs the taste of tea, coffee, and other beverages. High concentrations of manganese may cause a dark brown or black stain on porcelain plumbing fixtures. As with iron, manganese may form a coating on distribution pipes. These may slough off, causing brown blotches on laundered clothing or black particles in the water. Manganese is an essential nutrient, and toxicity is not expected from levels that would be encountered in drinking water. The provisional health based guideline value for manganese is 0.4 mg/L (Shelton and Scibilia, 2005)

2.5.11 Nitrate and Nitrite

Nitrate and nitrite are naturally-occurring ions that are part of the nitrogen cycle. Nitrate is used mainly in inorganic fertilizers, and sodium nitrite is used as a food preservative, especially in cured meats. The nitrate concentration in groundwater and surface water is normally low but can reach high levels as a result of leaching or runoff from agricultural land or contamination from human or animal wastes as a consequence of the oxidation of ammonia and similar sources. Anaerobic conditions may result in the formation and persistence of nitrite. Chloramination may give rise to the formation of nitrite within the distribution system if the formation of chloramine is not sufficiently controlled. The formation of nitrite is as a consequence of microbial

activity and may be intermittent. Nitrification in distribution systems can increase nitrite levels, usually by 0.2–1.5 mg/L. The guideline value for nitrate is 50 mg/L (WHO, 2006). Nitrification can adversely impact the distribution system by increasing nitrite and nitrate levels, reducing alkalinity, pH, dissolved oxygen, and chloramine residuals, and promoting bacterial regrowth (Wilczak *et al.* 1996). Nitrate and nitrite have direct health implications. Nitrate is transformed to nitrite in the human digestive system. The nitrite ion oxidizes iron in the haemoglobin of the red blood cells to form methemoglobin, which lacks the oxygen-carrying ability of haemoglobin. This creates the condition known as methemoglobinemia (commonly referred to as “blue baby syndrome”), in which blood lacks the ability to carry sufficient oxygen to the individual body cells causing the veins and skin to appear blue. Infants under 6 months of age and older persons with genetically impaired enzyme systems are unable to reduce toxic methemoglobin to oxyhaemoglobin. Therefore, ingestion of nitrite and nitrate can be fatal in these susceptible population groups (Runyan, 2002).

2.5.12 Faecal Coliform

Escherichia coli (*E.coli*) is considered the most suitable index of faecal contamination. *Escherichia coli* are the first organism of choice in monitoring programmes for verification, including surveillance of drinking-water quality. Water temperatures and nutrient concentrations are not generally elevated enough within the distribution system to support the growth of *E.coli* (or enteric pathogenic bacteria) in biofilms. Thus, the presence of *E.coli* should be considered as evidence of recent faecal contamination. Detection of *E.coli* should lead to consideration of further action, which could include further sampling and investigation of potential sources

such as inadequate treatment or breaches in distribution system integrity (WHO, 2006).

2.6 Distribution system pipes

Distribution system pipes are generally made of asbestos cement, unlined cast iron, cement-mortar-lined cast or ductile iron, plastic (PVC, HDPE), reinforced concrete, steel or fiberglass. Pipe materials used by the water utilities have changed greatly over time. Cast iron pipe (lined or unlined) has been largely phased out primarily due to its susceptibility to both internal and external corrosion. Early on, ductile iron pipe (with or without a cement lining) took its place because of its durability, strength and good resistance to external corrosion from soils. However, ductile iron pipe also needs corrosion protection in certain soils and may require multiple types of joints. Subsequently, concrete, asbestos cement, and polyvinyl chloride (PVC) plastic pipe were used to replace metal pipe because of their relatively good resistance to corrosion. More recently, high-density polyethylene (HDPE) pipe is being used as a replacement because of its ease of installation, toughness, flexibility, and corrosion resistance (USEPA, 2008).

2.7 Trends relevant to the deterioration of water in distribution systems

2.7.1 Biofilm growth

Different definitions for biofilms have been published in literature (LeChevallier, 1999a; Berger *et al.*, 1993; Characklis and Marshall, 1990). There is not one universally recognized definition for biofilms; however, common among the definitions is that a water distribution system biofilm is a complex mixture of

microbes, organic and inorganic material accumulated amidst a microbially produced organic polymer matrix (slime layer) attached to the inner surface of the distribution system. Figure 2.1 shows a picture of biofilm growth inside a pipe. The slime layer helps trap additional organic particles that many bacteria can use for food and energy. Other microorganisms including viruses, protozoa, algae, fungi, and helminthes may become associated with or entrained within the biofilm. Some protozoa graze on biofilm bacteria creating a food web. Biofilms provide a number of advantages for attached organisms compared to free-floating (planktonic) organisms. In a low-nutrient environment, it is easier for microbes to let the nutrients come to them rather than to search for the nutrients. The slime layer allows metabolic byproducts or wastes to accumulate, some of which may be used as food by other microorganisms, forming a cooperative ecology. The biofilm also protects the inhabitants from the effects of disinfectants. Biofilm microbes are many times more resistant to disinfection than planktonic microbes. Virtually every water distribution system is prone to the formation of biofilms, regardless of the purity of the water, type of pipe material, or the presence of a disinfectant. Growth of bacteria on surfaces can occur in the distribution system or in household plumbing. The inner surface of a water pipe may have a continuous biofilm, but usually biofilms are quite patchy (Walch, 1992; van der Wende and Characklis and Marshall, 1990).

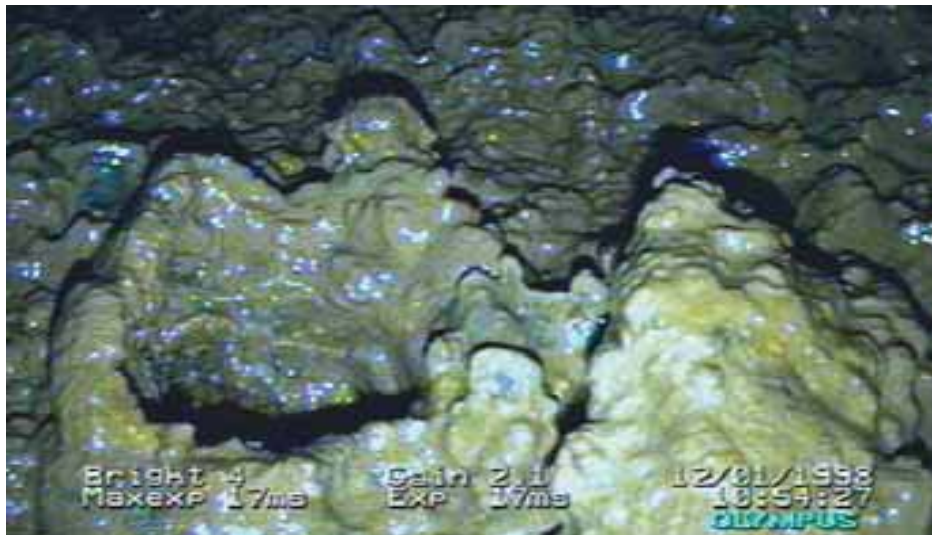


Figure 2.1: Biofilm growth inside the pipe (Source: USEPA, 2008)

Biofilms are complex and dynamic microenvironments that include processes such as metabolism, growth, and product formation, and finally detachment, erosion, or “sloughing” of the biofilm from the surface. The rate of biofilm formation and its release into a distribution system can be affected by many factors including surface characteristics, availability of nutrients, and flow velocities. Biofilms grow until the surface layers begin to slough off into the water (Geldreich and Rice 1987). In addition, biofilms may increase pipe corrosion (microbially induced corrosion), adversely affect pipe hydraulics. Microbial growth in biofilms may result in deterioration of water quality, generation of bad tastes, colours, and odours, and proliferation of macroinvertebrates (USEPA, 2002b). Microbes most often linked to aesthetic problems in drinking water are the actinomycetes, iron and sulphur bacteria, and algae, especially the blue-green algae (Cohn *et al.*, 1999; AWWA, 1995; Burlingame and Anselme, 1995). Many algal species and some actinomycetes produce geosmin and 2-methylisoborneol, both of which produce earthy-musty odours. Some *pseudomonads* can also produce foul-smelling sulphur compounds. The bacteria in the genus *Hyphomicrobium*, when sloughed off a biofilm, can cause episodes of black water (van der Wende and Characklis, 1990). Biofilms have been

implicated in infections and tuberculosis-like disease in the immunocompromised population, particularly those with AIDS (Horsburgh, 1991; Nightingale *et al.*, 1992). Many environmental strains of coliform bacteria such as *Citrobactor*, *Enterobactor*, and *Klebstella* may also colonise distribution systems (Martin *et al.*, 1982).

The elimination of biofilms is essentially impossible and their control is difficult. Attempts to eliminate them are complicated by the observation that conditions that reduce the numbers of organisms of one type may potentially support growth of others. In general, biofilms can be managed by removing organic matter during water treatment that would support biofilm growth, judicious use of disinfectants, good distribution hygiene practices such as flushing, minimizing the corrosion of iron pipe surfaces, and managing contamination from external sources.

2.7.2 Intermittent Water Supply

Intermittent water supply may be defined as a piped water supply service that delivers water to users for less than 24 hours in 1 day (McIntosh, 2003). It is a type of service that, although little found in developed countries, is very common in developing countries.

The primary cause of intermittent water supply is extending distribution systems beyond their hydraulic capacities to provide 24-hour service. This is usually done at the behest of elected officials (McIntosh, 2003). In Kathmandu, for example, they continue to add 5,000 new connections a year, despite an inadequate distribution system (McIntosh, 2003). Other causes of intermittent supply are a failure to meter completely and accurately and a failure to charge and collect on sufficiently high tariffs. It is often said that there is not enough water for 24-hour supply. This is not valid, because much of the water available is wasted. What is needed is demand

management (McIntosh, 2003). Leakage and illegal connections, contributes to intermittent water supply by lowering water pressure in the distribution system. One reason given for designing systems to provide water intermittently is the high cost of pumping for 20-24 hours.

Water from an intermittent water supply system is at risk of contamination, because under vacuum conditions foul water can be drawn into the pipes. (McIntosh, 2003).

2.7.3 Main Breaks, Repairs and Installation

Water main construction or repairs are most commonly done in open trenches or excavations. Therefore, during construction activities, the interiors of pipes and fittings can come into contact with soil and water in the trench. In addition, the chance of soil and water contacting pipe materials during construction or repair activities is potentially much greater than it is during storage and handling prior to construction/repair. The damp soil of a main repair trench is a potential source of bacterial contamination during repairs (USEPA, 2002a).

When a pipe-break or failure occurs, there is immediate potential for external contamination from soil, groundwater, or surface runoff (Kirmeyer *et al.*, 2001) to enter the distribution system or come into contact with the pipe interior in the area of the failure and be carried to downstream consumers. Additionally, installation, rehabilitation, and repair of water mains and appurtenances provide an opportunity for microbial and chemical contamination of materials that come into direct contact with drinking water. Water lines (mains and service lines) can be susceptible to contamination if they experience a break or opening and are in close proximity to sewer lines. This condition could result in contamination of the water main if the sewer line leaks and the water main experiences low or negative pressures, such as in

the case of an intrusion event. In 1989, waterborne disease outbreak in Cabool, Missouri in the United State was associated with water meter repair and two large water main breaks (Clark *et al.*, 1991; Geldreich *et al.*, 1992). The USEPA white paper, *New and Repaired Water Mains* (AWWA and EES, Inc., 2002), states that about 5 percent of reported waterborne disease outbreaks attributed to distribution system deficiencies in the United States over a 27-year period were associated with new or repaired water mains. Haas *et al.* (1998) reported that interior pipe surfaces are not free of microbial contaminants even under best case conditions. Thus, when a new main is installed or a valve is repaired, it is advisable to act as if some level of contamination has occurred to both the water and the materials. In both cases testing is required, and care should be taken to address potential contamination before the affected portion of the water system is returned to use. Prevention of contamination can also be facilitated by including the existing standards and additional training on sanitary practices in distribution system operator training requirements and sanitary survey guidelines. There is more variability in practices when it comes to preventing contamination during main breaks and failures than with the installation of new mains. Because water main repairs are of varying complexity and occur under a variety of environmental conditions, and due to their unplanned nature the repair may require quick response and return to service. The application of the same level of specifications used for new water mains may not be feasible.

The chemical and microbial contamination of distribution system materials and drinking water during mains breaks and during the installation, rehabilitation, and repair of water mains and appurtenances is a major challenge to water utility operators.

2.7.4 Disinfection and Disinfection By-Products (DBPs)

Water is disinfected to kill any pathogens which pass through the filters. Possible pathogens include viruses, bacteria, including *Escherichia coli*, *Campylobacter* and *Shigella*, and protozoans, including *G. lamblia* and other Cryptosporidia. Most utilities using surface water sources disinfect their water prior to delivery to their consumers. The intent of this requirement is to provide a barrier against disease-causing microorganisms. Some of the most commonly used disinfectants are chlorine and chloramines. Furthermore, it is necessary that a residual disinfectant be maintained throughout the distribution system. Loss of disinfectant residual is one of the most common water quality concerns. Following the introduction of any chemical disinfecting agent, the water is usually held in temporary storage called a clear well to allow the disinfecting action to complete. The availability of a disinfectant residual is a function of time and rate of decay or loss caused by consumption of disinfectant at the pipe wall and in the bulk water (USEPA, 2008).

Excess disinfectant levels lead to undesirable changes in water quality when the disinfectants react with naturally occurring organic matter or compounds, such as total organic carbon (TOC) or bromide, in the source water/distribution system to form Disinfection By-Products (DBPs) (USEPA, 2008). Although a disinfectant residual is generally necessary to maintain water quality, it is recognized that an excessive amount of disinfectant residual may also pose a threat to health by contributing to the increased formation of harmful DBPs. Natural organic matter contained in water (in the form of humic and non-humic [or fulvic] substances) serves as a precursor in DBP formation. Natural organic matter belongs to a family of compounds having similar structural and chemical properties and is formed during the decomposition of carbon-based life forms. The natural organic matter reacts with the residual disinfectant (e.g.,

chlorine, chloramine) in the distribution system to form DBPs such as chloroform, bromodichloromethane, and haloacetic acids (HAAs). Many of these DBPs are suspected of causing cancer, reproductive and developmental problems in humans (USEPA, 2005).

To minimize the formation of DBPs, USEPA has promulgated regulations that specify maximum residual disinfectant level goals for chlorine, chloramines, and chlorine dioxide. In addition, maximum contaminant levels (MCLs) for trihalomethanes (THMs) and HAAs have been established at 0.080 mg/L and 0.060 mg/L, respectively. In order to meet these requirements, utilities should carefully evaluate the key variables that impact their formation including: residual disinfectant levels, water age in the distribution system, TOC concentration, pH, and water temperature (USEPA, 2005).

2.7.5 Corrosion and Scale Formation

Corrosion is the gradual deterioration of metal pipes, metal fixtures, cement mortar lining in pipes, or other substances because of a reaction with the water (AWWA, 1999). Corrosion can be the result of physical actions that erode the coating of a pipe, chemical dissolution that leaches a pipe's lining or wall material, or electrochemical reactions that remove metal from the wall of the pipe (AWWA, 2000). Pipe material invariably erodes with time. The rate of this process is affected by the composition of the pipe, the corrosivity of the water within the pipe and the soil and water external to the pipe, the microbial activity in the pipe biofilm, and other factors (Geldreich, 1996). Over time, corrosion may become serious enough to restrict water passage, produce taste and odour problems, cause pipe breaks, and accelerate biofilm development (Geldreich, 1996). Internal corrosion of iron pipes reduces their

structural strength and may create leaks and bursts, as does external corrosion. In addition to weakening pipe walls, internal corrosion also increases the consumption of disinfectant residual, development of large tubercles as illustrated in Figure 2.2 (collections of material that may include scale, algae, and bacteria) inside the pipes, reducing water-carrying capacity and water pressure which in turn increases residence times and creates deposits that are undesirable in terms of maintaining high microbial quality (LeChevallier *et al.*, 1993). Biological growths within the distribution system can also cause corrosion by providing an environment in which physical and chemical interaction can occur. Microbes involved in the oxidation of iron and steel surfaces can deposit oxides of iron and manganese in raised hard outgrowths from the pipe known as tubercles (Walch, 1992). Corrosion does not necessarily affect the safety of drinking water directly, but it will reduce the life of the pipes and, in older pipes, increase the probability of leaks, breaks, and contamination.

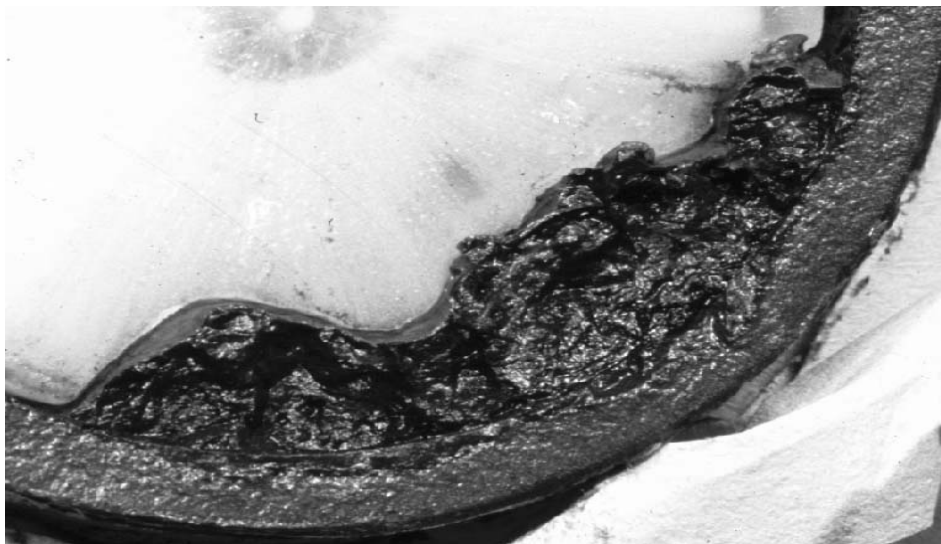


Figure 2.2: Corrosion tubercles in an old cast iron main.

It is essential to maintain a stable pH in order to maintain distribution system water quality. Low pH values (less than 7.0) can accelerate the internal corrosion of metallic

pipes, therefore, a certain level of scaling in metallic pipes is helpful in passivating the pipe by depositing a protective carbonate layer on it. However, higher pH (greater than 9) can cause excessive scale formation which can significantly reduce the carrying capacity of a pipe and provide a shelter for biofilm growth (USEPA, 2008). Scales based on adhesive and layered calcium carbonate deposits can form in mains when the conveyed water is excessively supersaturated with calcium carbonate. These may also be found in association with corrosion products and biofilms (Lu *et al.*, 1998). Scale formation is a complicated process that depends on a variety of system-specific physical and chemical conditions. Scale-forming potential is often measured by the calcium carbonate precipitation potential. Calcium carbonate deposits and ferrous corrosion products usually require mechanical action or an acid chemical process for their removal. To prevent corrosion and scale, the water should be saturated or slightly over-saturated with calcium carbonate (Legrand & Leroy cited in Levi, 2004). It is also important to consider how changes in water composition may affect the corrosion of all distribution and plumbing materials. Guidance is available for minimizing corrosion in networks containing pipes made from iron, lead, copper, galvanised steel and cement based materials (UKWIR, 2000).

2.7.6 Sediment build-up

In addition to iron and manganese build-up in storage facilities because of chemical precipitation, other suspended materials present in the source water may settle out in storage facilities. Particulates may be introduced to the distribution system if the water treatment facility is not working properly. Sediment frequently accumulates in storage tanks where the velocities are minimal. Sediment can be resuspended because of surges in flow, and sediment is a potential cause of water quality degradation by

contributing to the water's chlorine demand. One utility traced elevated levels of coliform bacteria in reservoir water to accumulated sediment (Beuhler *et al.*, 1994). In another study, the authors speculated that a taste and odour problem was linked to the bottom sediment, where substrate is abundant for diverse biological growth (Burlingame and Brock, 1985). Block *et al.* (1996) collected sediment samples from finished water-storage facilities and water mains and determined their composition. The sediment samples varied in their appearance, with colours ranging from reddish to yellow-brown to dark brown. The samples of reservoir sediment had the following composition: insolubles (18 percent), iron oxides (19 percent), volatile solids (19 percent of total), aluminum hydroxides (15 percent), calcium carbonates (10 percent), and unknown (16 percent). Block *et al.* (1996) reported that the reservoir and pipe sediment samples were heavily colonized by microorganisms. One method of preventing the accumulated sediments from re-entering the distribution system once settling in a storage facility has occurred is to install a riser pipe on the outlet. Avoiding flow fluctuations that would scour the bottom surface or changing the inlet-outlet configuration to improve flow patterns also may keep the sediments from re-entering the distribution system. In the case of an improperly operated water treatment plant, a plant evaluation to determine more effective treatment operations may be beneficial. Cleaning the storage facilities to minimize sediment build-up also is important. Flushing of the distribution system to remove accumulated sediments before they reach the storage facility is in order as well.

2.7.7 Finished Water Storage

Storage facilities for treated water are of vital importance for drinking water distribution systems. Storage facilities are conventionally designed and operated to

secure system hydraulic integrity and reliability, to provide reserve capacity for fire fighting, power outage and other emergencies, to equalize system pressure, and to balance water use throughout the day. To achieve these targets, large volumes of reserve storage are usually integrated into system operation and design, resulting in long detention times (USEPA, 2002a). Long detention times and improper mixing within such facilities afford an opportunity for both chemical and microbial contamination of the water. One of the most important manifestations of water quality deterioration during water storage is a loss of disinfectant residual due to water age. Although the loss of disinfectant residual within a storage facility does not necessarily pose a direct public health threat, however, disinfectant decay can contribute to biofilm growth and related problems. The rate of residual disinfectant decay can be further affected by external contamination, temperature, nitrification, exposure to ultraviolet light (sun), and the amount and type of chlorine demanding compounds present such as organics and inorganics (USEPA, 2002a).

Sediment accumulation may also occur within storage facilities due to quiescent conditions which promote particle settling. Potential water quality problems associated with sediment accumulation include increased disinfectant demand, microbial growth, DBP formation, and intermittent increased turbidity within the bulk water (USEPA, 2002a). Internal chemical contamination can also occur due to leaching from coatings used in the storage facility, or solvents, adhesives, and other chemicals used to fabricate or repair floating covers. In addition to the internal degradation of water quality that occurs over time in water storage facilities, storage facilities are also susceptible to external contamination from birds, animals, wind, rain, and algae. This is most true for uncovered storage facilities, although storage facilities with floating covers are also susceptible to bacterial contamination and

regrowth from untreated water that collects on the cover surface. Even with covered storage facilities, contaminants can gain access through improperly sealed access openings and hatches or faulty screening of vents and overflows (USEPA, 2002a). In December 1993 Clark *et al.* (1996) reported that in Gideon, Missouri, a *Salmonella typhimurium* outbreak occurred due to a bird contamination of a covered municipal water storage tank (Clark *et al.*, 1996).

Water quantity and quality requirements in distribution storage management decisions are frequently in conflict. While water quantity objectives promote excessive storage, water quality objectives are geared toward minimizing residence times and frequent exercising of treated water facilities to maximize the stored water disinfectant residual. Appropriate balancing is therefore required to ensure disinfection effectiveness and sufficient level of service (Boulos *et al.*, 1996; Hannoun and Boulos, 1997).

Proper operation of storage vessels can reduce excessive residence times, which in turn leads to reduction in microbial survival and growth, and biofilm formation. Properly designed inlets and outlets, and the overall system design can resolve problems caused by dead ends (Trussell, 1999). Adequate turnover of the water in finished water storage facilities minimize nutrient availability and prevent the accumulation of sediments. To accomplish this, systems can exercise valves to reduce stagnation and eliminate excess storage (Crozes and Cushing, 2000). Systems can exercise additional control over biofilm accumulation and microbial growth in finished water storage vessels by preventing sediment accumulation. This can be accomplished through periodic flushing (Crozes and Cushing, 2000) and cleaning. Pathogen contamination due to air introduction can be reduced by installing air filters to guard against pollution entering covered water reservoirs (USEPA, 1992). An

understanding of the storage hydraulics and operation is important in reducing contamination of the finished water.

CHAPTER THREE

3 STUDY AREA, MATERIALS AND METHODS

3.1 Background of the study area

Kumasi the capital of Ashanti Region is a city in southern central Ghana with a metropolis covering an area of about 245 km². Kumasi is approximately 480 km north of the equator and 160 km north of the Gulf of Guinea. Kumasi is currently the second most urbanized city in the country with a population of 4,725,046 estimated in the provisional 2010 census. Ashanti Region lies within the wet semi-equatorial zone marked by double maximum rainfall ranging between 1 150 mm and 1 1750 mm per annum. The major rainfall season is from April to July and the minor season is between September and Mid-November.

Kumasi has been demarcated by Ghana Urban Water Limited (GUWL) into 8 water distribution districts namely: Central, North, West, North East, South, North West, South East and East (Figure 3.1A). The two households in Adum chosen for the water quality assessment falls under the central district as shown in Figure 3.1B.

Central District

The localities forming the Central district are: Adum, Ridge, Pine Avenue, Dakojom, Army Barracks, Kejetia, New Asafo, Dadiesoaba, Bimpeh Hill, Fanti New Town, Roman Hill, Bompata, Central Market, Alla Bar, South Zongo, Duako Abrampong, New Amakom, Old Amakom, Lobito, Old Asukwa, New Asukwa, and Danyame.

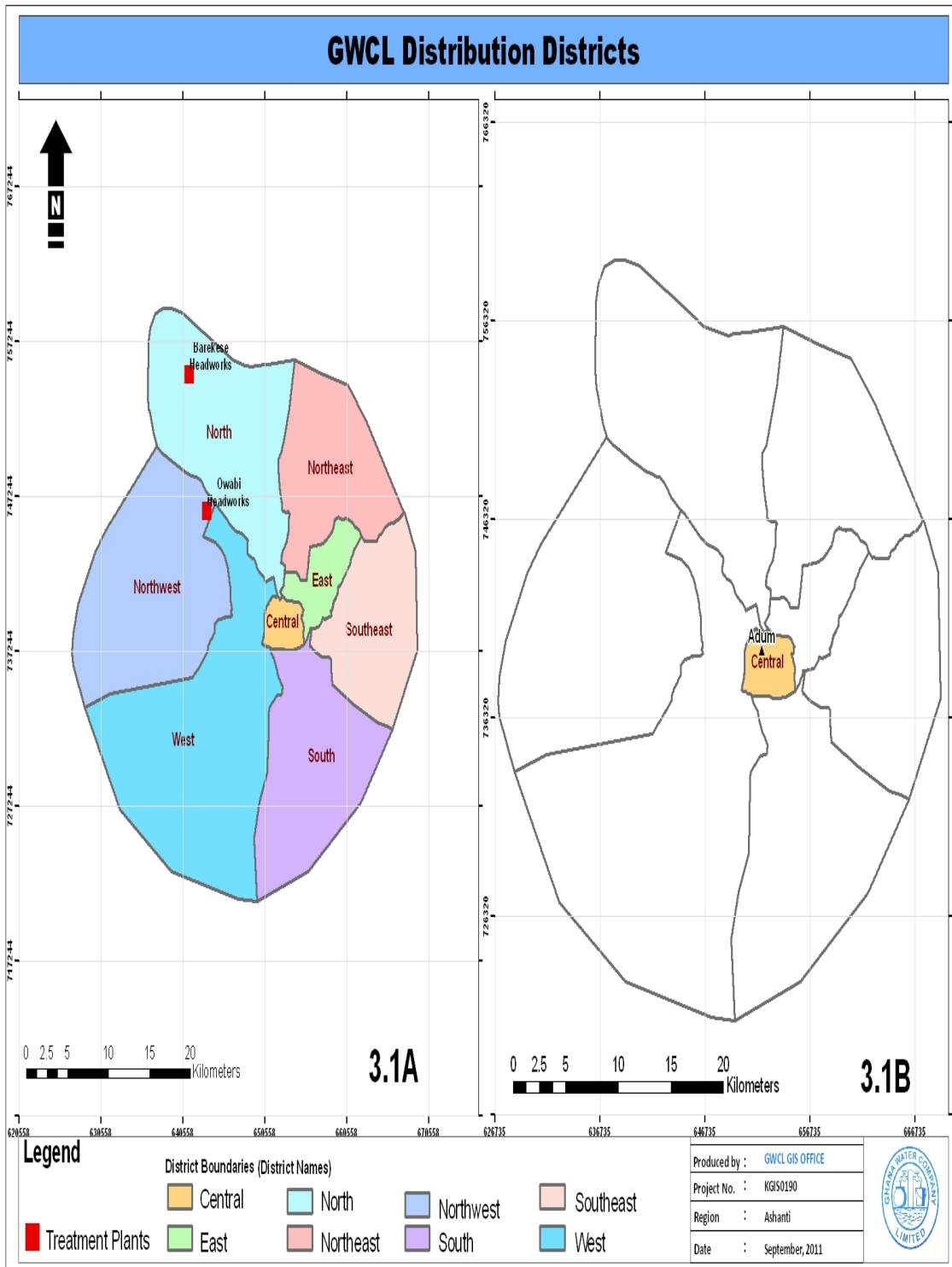


Figure 3.1A: Map showing the GWCL eight (8) water distribution districts.

Figure 3.1B: Map of central district indicating study area (Adum).

Main source of water supply in Kumasi

The main source of water supply in Kumasi is pipe-borne water from the Barekese and Owabi head works produced and distributed by GUWL. The Owabi reservoir is about 135 m long, 11 m high and has a spillway crest at +227.5 m. This stone masonry gravity dam was constructed in 1928 with a reservoir capacity of 6.2 Mm³ located about 8 km west of Kumasi. The Owabi Water Treatment Plant originally had a capacity of 4500 m³/day but in 1954, a new plant with a capacity of 13 500 m³/day was constructed and rehabilitated in 1989 (Kuma *et al.*, 2010). The Barekese reservoir is an earth filled dam with rock protection constructed between 1967 and 1971. The reservoir is 15 m high and 600 m long with a 77 m wide concrete spillway that has a crest elevation of +220.98 m. The original storage capacity of the Barekese reservoir is 35.3 Mm³ with an ultimate design capacity of 218 400 m³/day but is considered to be heavily silted (Blokhuis *et al.*, 2005). Major expansion and rehabilitation works were undertaken in 1998 with an expected daily production capacity of 81 830 m³/day. However, the average daily output is 59 392 m³/day (Kuma *et al.*, 2010).

Treated water is pumped from Barekese and Owabi headworks through steel and iron mains for 22 km and 14 km respectively to Suame where it is centrally monitored. Two ground and one elevated reservoir with a total capacity of 13 800 m³ store water at Suame. Calcium hypochlorite is used to “refresh” the water received from the water treatment plants (Blokhuis *et al.*, 2005)

Approximately 580 km of pipelines with diametres ranging between 13 mm and 600 mm distribute water within the Kumasi Water Supply System (KWSS). About 37 km of grey cast iron pipes which are 60 years or more are located mostly in the city centre

and are inaccessible. In other parts of the city transmission and distribution mains are exposed resulting in frequent leaks and bursts. The quality of water is monitored in a central laboratory at Suame and at 150 other points in the distribution system (Blokhuis *et al.*, 2005). The Table below (Table 3.1) shows the actual number of customers served by GUWL in Kumasi City.

Table 3.1: GUWL customer population distribution

GUWL Districts	Connected Customers
Central	6971
East	8891
North	14739
North East	7020
North West	6582
South East	2966
South	6955
West	12312

Source: GUWL Digital (GIS) office, July 2011.

3.2 Desk study

This aspect of the study was conducted to gather all relevant data on the research topic. Data which were obtained from the field and laboratory experiments, questionnaire administration and interviews were analysed.

3.3 Location and collection of water samples

A total of 50 water samples were collected aseptically from the Barekese head-works Suame reservoir and the household taps over one and half month period (July to August, 2011). Sampling of household tap water was done at two sites in Adum.

Sampling was conducted at two weeks interval. The Table below (Table 3.2) shows the frequency of sampling. The sampling locations are illustrated in Figure 3.2. The two projections named A and B in Figure 3.2 show clearly the sampling sites at the Suame reservoirs and the household respectively. Meaningful and reliable sampling assures the validity of analytical findings. Therefore, utmost care was exercised to ensure that the analyses were representative of the actual composition of the samples. Samples for physicochemical analysis were stored in clean 1.5 litre plastic bottles. Samples for metals were collected in 1.5 litre plastic bottles and acidified with concentrated nitric acid to a $\text{pH} < 2$. Microbiological samples were collected in sterile autoclavable 1 litre screw-necked glass bottles. Duplicate samples were collected at the headworks for the microbiological test.

Prior to filling, the sample bottles were rinsed two to three times with the water to be collected. The spout of the taps was cleaned and flame sterilized using cotton soaked with methanol for 30-60 seconds before sampling. Samples were taken after allowing the tap to flow for about 5 minutes to avoid the use of stagnant water in the network. Plastic bucket on the end of a nylon rope was used to collect samples from Suame reservoirs.

Table 3.2: Summary of sampling schedule

Sample location	Total number of samples collected	Sampling time	Sampling Period
Barekese HW	10 samples	9am and 12noon	Biweekly
Suame reservoir	10 samples	9am and 12noon	Biweekly
Household-A (Adum)	15 samples	9am, 12noon and 4pm	Biweekly
Household-B (Adum)	15 samples	9am, 12noon and 4pm	Biweekly

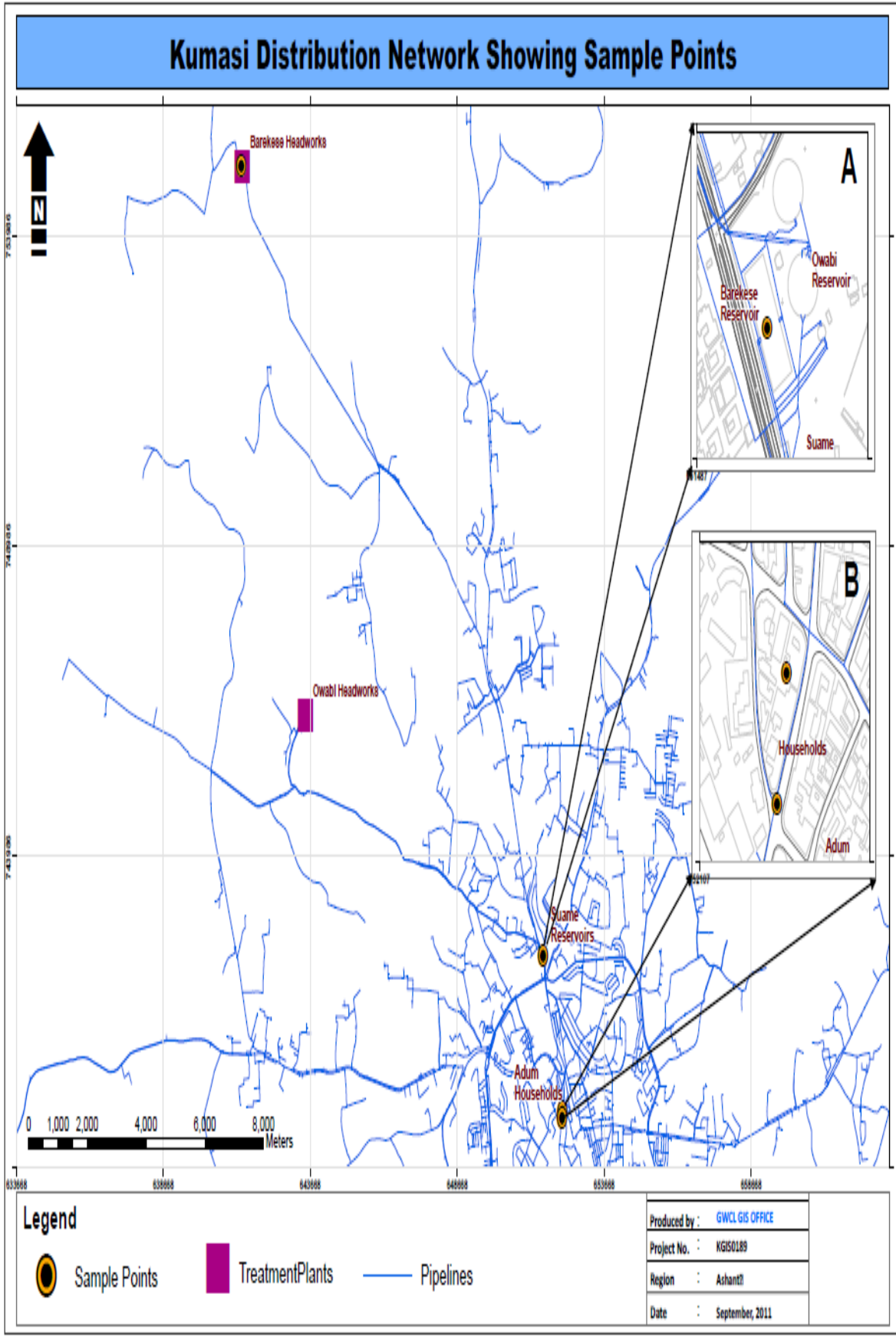


Figure 3.2: Map of GUWL distribution network showing sampling locations

Equipment like residual chlorine meter, pH and turbidity meter which were used on-site were calibrated before use. On-site analyses were carried out for parameters like pH, temperature, turbidity, residual chlorine and conductivity. Collected samples were preserved in an ice chest at 4°C and taken to the Department of Civil Engineering of KNUST laboratory after 6 hrs of collection, and the bacteriological samples analysed immediately. The other parameters were analysed within two days. The Table below (Table 3.3) shows the preservation method used, and maximum holding time between sampling and analysis, if any, for each parameter.

Table 3.3: Maximum delay between sampling and analysis and preservation method

Parameter	Preservation	Maximum holding time
Temperature, Turbidity, pH, Conductivity, Total Dissolved Solids,	Nil	Nil (on-site analysis)
Free residual chlorine	Nil	Nil (on-site analysis)
ammonia, Nitrate	Nil	1 day
Total Hardness, calcium hardness, total alkalinity	Nil	1 day
Calcium, magnesium, total iron, manganese	HNO ₃	1 day
Faecal coliform, <i>E.coli</i> , <i>salmonella</i>	Thermos flask filled with ice cubes	6 Hrs

3.4 Customer perception survey

3.4.1 Purpose of survey

The purpose of this survey was to measure customer perception of GUWL services. It also provides a measure of GUWL performance from the point of view of the customers. The survey measured indicators such as customer perception on the quality of water delivered and flow conditions.

3.4.2 Design of survey instrument

A structured questionnaire was designed and pre-tested with 10 customers to check whether the wording and responding categories of the questionnaires were appropriate for the survey population, and to eliminate any ambiguous questions. Based on the pre-testing the questionnaires were improved for the execution of the survey.

3.4.3 Sampling

A convenient sample of fifty (50) household was drawn from consumers connected to GUWL distribution system. The questionnaires, fifty (50) in number were administered to 50 customers at Adum in the Kumasi metropolitan area in September 2011. The questionnaires were administered by hand to the respondents. The head of the household or any adult person was preferred to as the respondent to the structured interview. In cases where the customers' or respondents' ability to read and respond in English were doubtful, I explained the questions and recorded their answer on the questionnaires. I also probed respondents to elaborate on some of their answers. Through this I was able to collect additional data in my field note book. In total, I had a 100% response rate.

3.4.4 *Manager's Survey*

In addition to consumer survey, a management survey was also carried out. Survey questions roughly used an open-ended question approach. The questions focused on tap water quality. Utility managers were asked to respond to questions from the view point of customers.

3.4.5 *Analysis of questionnaires*

Once an interview was completed, data was entered into a statistical program (SPSS) used for data analysis. The questionnaire data was coded and entered into SPSS and analysis results exported to Excel™ (2007 version). General statistics (e.g., frequencies, bar charts, and pie charts) were run and chi-squared analysis performed on the various perception variables.

3.5 *Field Analysis of Water Samples*

3.5.1 *Temperature, pH, TDS and EC*

The electrical conductivity (EC), temperature, total dissolved solids (TDS), pH were analysed on-site using a digital kit, a PC 300 waterproof handheld pH/Conductivity/TDS/Temperature meter. A digital reading appears upon inserting the probes into the sample indicating first the values of pH and temperature. The sample is stirred and the digital reading allowed to stabilise before recording. The “MODE” button which allows switching to other parameters is then used to read the values of TDS and EC. Table 3.4 presents the place for samples analysis (on-site or laboratory) and instrument or method of analysis.

Table 3.4: Method of sample analysis

Parameters	Place of Analysis	Instrument/Method used
Temperature, TDS, pH and Conductivity	On-site	Electrode
Turbidity	On-site	Electrode
Nitrate, Ammonia	Laboratory	Spectrophotometer
Total Hardness and Calcium hardness	Laboratory	EDTA titration
Alkalinity	Laboratory	H ₂ SO ₄ titration
<i>E.coli</i> , <i>Salmonella</i> and faecal coliform	Laboratory	Membrane filtration

3.5.2 Turbidity and Free Residual Chlorine (F Cl)

Formazine standard solution made up of hydrazine sulphate ((NH)₂.H₂SO₄) and hexamethylenetetramine (C₆H₁₂N₄) was used to calibrate the Hanna turbidity, free and total chlorine meter (HI 93414 model) for turbidity measurement. For free/total chlorine measurement the Hanna metre was calibrated with standards provided by the manufacturers.

Turbidity

A clean, dry glass cuvet was filled with 10 ml of the sample. Silicone oil was applied on the cuvet and wiped with a lint-free cloth to obtain an even film over the entire surface of the cuvet. The cuvet was placed into its holder in the Hanna HI 93414 turbidity and free/total chlorine meter with its mark aligned with that of the instrument. The turbidity range was selected. When READ/ENTER was pressed, the display showed blinking dashes, after which the result in NTU was displayed and recorded accordingly.

Free Residual chlorine (F Cl)

The free chlorine (F Cl) range was selected, the 'ZERO' tag blinked suggesting that a zero measurement should be done. 10 ml of sample was measured into the cuvet and placed in the instrument such that the mark on the cuvet coincided with that of the instrument. When ZERO/AVG was pressed dashes blinked and then "-0.0-" indicating that successful zeroing had been done. The cuvet was then filled with 10 ml of the sample and the appropriate reagent added. The cuvet was capped and then shaken gently for 20 seconds. It was placed into its holder with the mark on it matching that of the instrument. READ/TIMER was then pressed for 3 seconds and the display showed the hourglass blinking and the countdown prior to measurement. The result in mg/L of free chlorine was displayed and recorded.

3.6 Laboratory Analysis

3.6.1 Total Hardness

The total hardness of the water samples were determined by titration with 0.01 M EDTA. The EDTA solution was poured into a burette. 50 ml of sample was pipetted into a 250 ml conical flask. 0.5 ml of buffer of pH 10 was added to the sample. 3 drops of 5% erichrome black T indicator was also added to sample. The solution was titrated slowly and stirred continuously until the last reddish tinge turned to blue. The last few drops of EDTA were added at 3-5 seconds interval.

$$\text{Total hardness (mg/l)} = (V \times M \times 100) \times \frac{1000}{\text{ml sample}}, \text{ where}$$

V = mL EDTA titrated

M = molarity of EDTA

100 = molecular mass of calcium carbonate

1000 = factor

3.6.2 Calcium Hardness

The calcium concentration of the water samples were determined by titration with 0.01 M EDTA. The 0.01 M EDTA was poured into the burette. 50 ml of sample was measured into a 250 ml conical flask. 2 ml of 4 M NaOH indicator was poured into sample. 0.4 g of Murexide indicator was also put into conical flask and the colour changed to light pink. The solution was then titrated with the 0.01 M EDTA. A reddish-brown colour developed at the end of the titration.

$$\text{Calcium hardness (mg/l)} = (V \times M \times 100) \times \frac{1000}{\text{ml sample}}, \text{ where}$$

$V = \text{mL EDTA titrated}$

$M = \text{molarity of EDTA}$

$100 = \text{molecular mass of calcium carbonate}$

$1000 = \text{factor}$

3.6.3 Alkalinity

The total alkalinity of the water samples were determined by titration with 0.02 M H₂SO₄ with methyl orange as the indicator. 50 ml of the sample was measured into a 250 ml flask and two drops of methyl orange indicator added and swirled to mix. It was then titrated against the 0.02 M H₂SO₄ with continuous swirling until the end point was reached.

$$\text{Total alkalinity (mg/l)} = (V \times N \times 100) \times \frac{1000}{\text{ml sample} \times 2}, \text{ where}$$

$V = \text{titration volume in mL}$

$N = \text{normality of acid solution}$

$100 = \text{molecular mass of calcium carbonate}$

$1000 = \text{factor}$

3.6.4 *E.coli*, *Salmonella* and Faecal Coliforms

Membrane filter technique using Chromocult Coliform Agar was employed. Chromocult Coliform Agar determines the presence or absence of coliform bacteria, *E.coli*, and *salmonella* in water. With a pair of sterilised forceps, a 0.45 µm membrane filter is placed into a sterilized filtration funnel. 100 mL of the water is poured into the funnel and then filtered through the micropore filter by vacuum suction, thereby capturing any coliforms. With the aid of sterile forceps, the filter

membrane is placed aseptically onto the Chromocult Coliform Agar in a Petri dish. The dish is inverted, closed and incubated at 35°C for 24 hours.

After 24 hours of incubation, the filter is examined for colony growths and then counted. The number of Salmon to red colonies is recorded as coliforms and green to turquoise colonies are counted as salmonella by visual examination while dark-blue to violet colonies are recorded as *E.coli*. The sum of these three colonies is recorded as total coliforms.

3.7 Analysis for Heavy Metals

The Buck 210VGP atomic absorption spectrophotometer was used to measure the concentration of elemental metals in solution.

Sample preparation and digestion

Samples were initially acidified with a known volume of concentrated nitric acid (one percent of sample volume) to prevent the bonding of heavy metals to the suspended solids. 30 ml of digestion mixture, HClO₄ and HNO₃ (ratio 4:9 respectively), was added to the resulting solution and mixed thoroughly. The mixture was heated gradually to about 150 – 200°C until production of red nitrite fumes ceased. Heating was further continued until the volume of the mixture was reduced to 3 to 4ml and became colourless ensuring that it was not totally dried. The mixture was allowed to cool and diluted to 50ml with distilled water.

Measuring concentration of heavy metals

The appropriate hollow cathode lamp was inserted in the selected lamp holder. Solutions which contain no analyte element representing the analytical blanks and a series of calibration solutions containing known amounts of analyte element (standard

solutions) were prepared. These standards and their blanks were atomized sequentially and their individual responses measured. A calibration curve indicating the response obtained for each solution was plotted. The sample solution was then atomized and the response measured. The concentration of the sample solution was determined from the calibration curve based on the absorbance obtained.

3.8 Spectrophotometric Analysis

In this research, a Hach DR/2400 Spectrophotometer was used in determining the concentration of Iron, Nitrates–nitrogen and Nitrogen–ammonia. The procedures involved are described below:

3.8.1 Iron

The concentration of iron was determined by initially selecting Program 265 Iron, FerroVer from the Hach Programs. A clean, round sample cell was filled with 25 mL of the sample and the contents of one FerroVer Iron Reagent Powder Pillow added to it. The sample cell was swirled to mix the contents and the timer icon pressed to begin a three-minute reaction period. Another sample cell was filled with 10 mL distilled water (the blank) and placed in the cell holder of the spectrophotometer after thoroughly wiping it. The ‘Zero’ button was pressed and a 0.00 mg/L Fe concentration was displayed. After the three-minute reaction period, the prepared sample was also placed in the cell holder and ‘Read’ button pressed. The concentration of iron was displayed in mg/L Fe.

3.8.2 Nitrate-nitrogen

The concentration of Nitrate-nitrogen was determined by selecting Program 353 N, Nitrate MR from the Hach Programs. A clean, round sample cell was filled with 25

mL of the sample and the contents of one NitraVer 5 Nitrate Reagent Powder Pillow added to it. The sample cell was shaken vigorously to mix the contents and the timer icon pressed to begin a one-minute reaction period. The timer icon was pressed again after the one-minute reaction for a five-minute reaction period to begin. Another sample cell was filled with 25 mL distilled water (the blank) and placed in the cell holder of the spectrophotometer after thoroughly wiping it. The 'Zero' button was pressed and a 0.00 mg/L NO₃-N concentration was displayed. After the five-minute reaction period, the prepared sample was also placed in the cell holder after wiping the sample cell and the 'Read' button was pressed. The concentration of Nitrate-nitrogen was displayed in mg/L NO₃⁻-N

3.8.3 Nitrogen-ammonia

The salicylate method was used.

Principle

Ammonia compounds combine with chlorine to form monochloramine. Monochloramine reacts with salicylate to form 5-aminosalicylate. The 5-aminosalicylate is oxidized in the presence of a sodium nitroprusside catalyst to form a blue colored compound. The blue color is masked by the yellow color from the excess reagent present to give a green-colored solution.

Procedure

Nitrogen-ammonia was determined by selecting Program 385 N, Ammonia, Salic. from the Hach Programs. A clean, round sample cell was filled with 25 mL of the sample and another sample cell filled with 25 mL deionised water (the blank). To each of these cells, the contents of one Ammonia Salicylate Powder Pillow were added. The cells were stoppered and shaken to mix the contents and the timer icon

pressed to begin a three-minute reaction period. After this period, the contents of one Ammonia Cyanurate Powder Pillow were again added to each cell, stoppered and shaken to dissolve the reagent. The timer icon was pressed to begin a 15-minute reaction period. The blank was first placed into the cell holder after the reaction period and the 'Zero' button pressed. A 0.00 mg/L $\text{NH}_3\text{-N}$ concentration was displayed. Subsequently, the prepared sample was also placed in the cell holder after wiping the sample cell and the 'Read' button was pressed. The concentration of Nitrogen-ammonia was displayed in mg/L $\text{NH}_3\text{-N}$.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

In this chapter, the results obtained from the laboratory and field tests from the Barekese headworks, Suame reservoir, households in Adum and the customer perception survey studies have been presented and discussed.

4.1 Laboratory and Field Test

A total of 50 piped water samples were collected from Barekese headworks, Suame reservoir and households at Adum. In totality samples from Barekese headworks, Suame reservoir and households contributed 20%, 20%, and 60% respectively.

The water quality values obtained for the water samples were compared with WHO guideline values and Ghana Standard Authority (GSA) standards to ascertain if the quality were in accordance with the drinking water standards. For the water quality analysis, physical, chemical and bacteriological parameters were assayed for.

4.1.1 Turbidity

The mean turbidity values recorded for the water samples ranged between 1.17 ± 0.27 to 2.43 ± 0.29 NTU (Figure 4.1) which was within the WHO/GSA permissible limits. WHO (1998) suggest that the appearance of water with a turbidity of less than 5 NTU is usually acceptable to consumers, although it may vary with local circumstances. High turbidity (>25 NTU) makes water unappealing to drink because of its milky appearance. High turbidity levels could be a strong indication of existence of suspended or colloidal particles in the water. The colloidal particles would reduce the efficiency of disinfection by creating a disinfection demand. Particles may also shield

disease-causing bacteria from chlorine or other treatment and provide nutrients for bacteria and viruses to flourish (WSDH, 2004 and WHO, 2008). The difference in turbidity levels of the water samples could be due to the dissolution of iron taken up within the distribution network. It could also be due to accumulation of sediments in the reservoir.

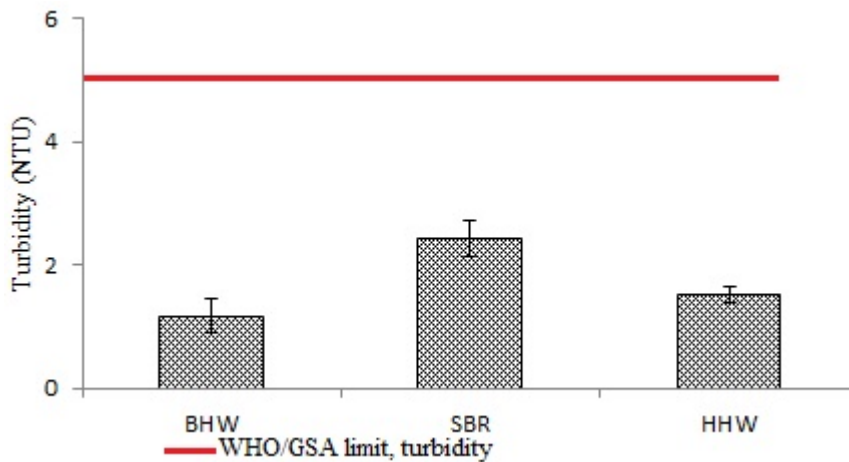


Figure 4.1: Turbidity of the water samples

BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples

4.1.2 Total Dissolved Solids (TDS)

The mean TDS recorded for the water samples ranged between 66.09 ± 1.94 and 85.69 ± 6.00 mg/L (Figure 4.2) which was within the WHO/GSA permissible limits. Water with more than 1000 mg/L of dissolved solids usually contains minerals which give it unpalatable taste (Al-Ruwaih *et al*, 2010). The palatability of drinking water has been rated by panels of tasters in relation to its TDS level as illustrated in Table 4.1. Water containing extremely low concentrations of TDS may be unacceptable because of its flat taste. An elevated total dissolved solids (TDS) concentration is not a health hazard as the TDS concentration is a secondary drinking water standard and is more

of an aesthetic rather than a health hazard. An elevated TDS may be an indicator of the concentration of dissolved ions which may cause the water to be salty.

Tab 4.1: Quality classification of drinking water (WHO, 2006)

Water class	TDS (mg/L)
Excellent	<300
Good	300-600
Fair	600-900
Poor	900-1200
Unacceptable	>1200

This information indicates that the produced drinking water may be excellent according to the WHO guidelines as shown in Table 4.1.

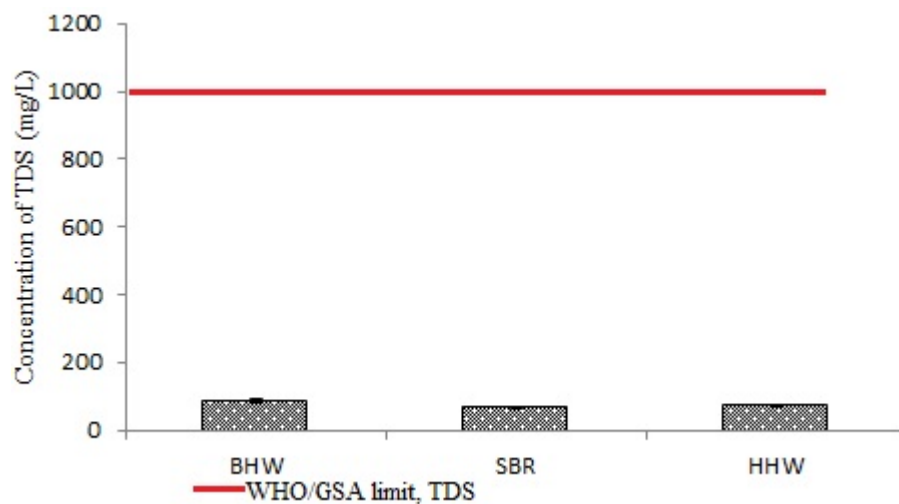


Figure 4.2: Occurrence of TDS in the water samples

BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples

4.1.3 Temperature

The mean temperature of the water samples varied from 25.75 ± 0.20 °C to 28.00 ± 0.26 °C as shown in Figure 4.3. Consumers often tend to prefer cool water to warm water. Warmer water may not be rejected by consumers because there are ways by which the temperature of water can be maintained to make it acceptable. Temperature affects the reaction rates and solubility levels of chemicals present in water. High temperatures can negatively impact water quality by enhancing microbial growth (Schindler, 1990 and WHO, 2006). There is no guideline value set by WHO and GSA.

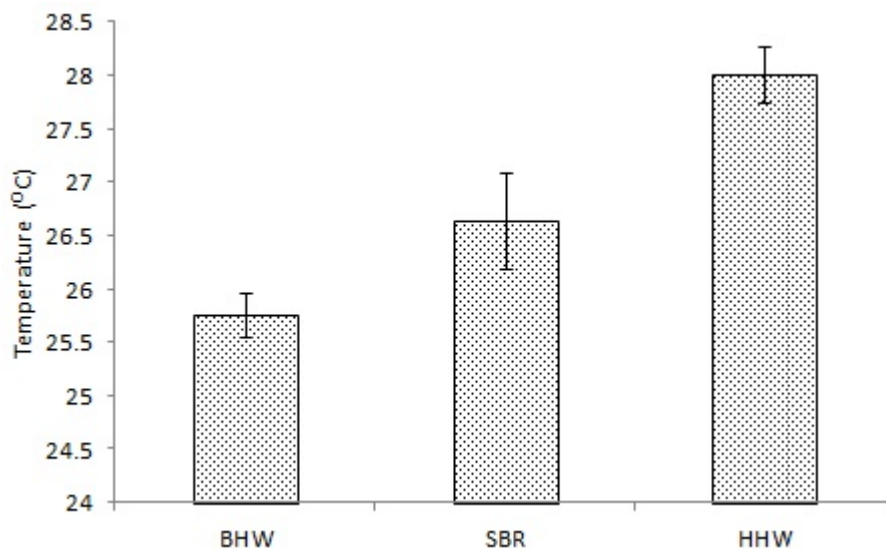


Figure 4.3 Temperature level of the water samples

BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples

4.1.4 Hardness

The mean total hardness recorded for the water samples ranged between 42 ± 2.37 and 62.9 ± 1.69 mg/L (Figure 4.4) which were below the WHO/GSA guideline value. The summation of calcium hardness and magnesium hardness is regarded as the total hardness of water. In the present investigation, it has been observed that the calcium hardness concentration is mostly two folds greater than that of magnesium hardness value. The impact of hardness is scale deposition and high soap consumption (WHO, 2006). The water samples can be classified as soft according to WHO, 2006 guideline values of a range of 0 to 100 mg/L for soft water. This might be corrosive to the water pipes.

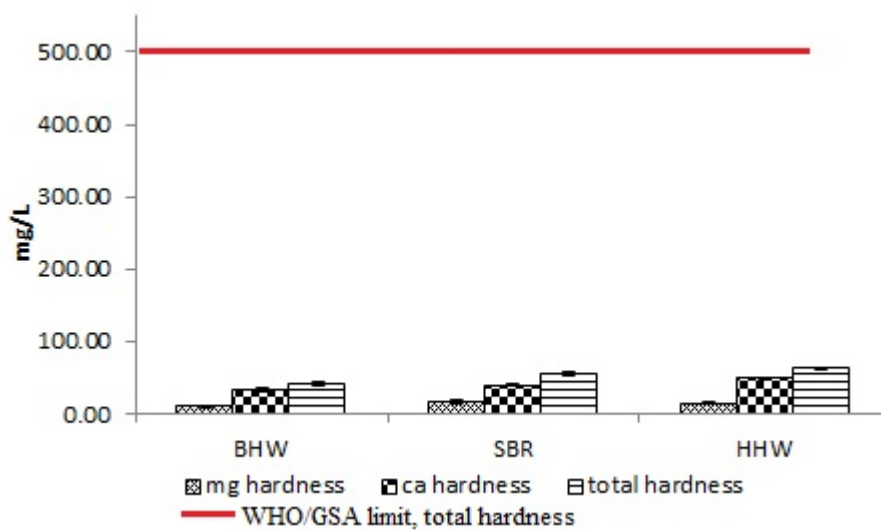


Figure 4.4: Mean Mg, Ca and total hardness of the water samples

BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples

4.1.5 Alkalinity

The mean alkalinity of the water samples ranged from 20.7 ± 1.28 to 30.8 ± 2.24 mg/L as shown in Figure 4.5. WHO and GSA have no guideline value for alkalinity.

The total alkalinity value of water is an indicator of the acid neutralizing ability of the water and is determined by how much carbonate, bicarbonate and hydroxide is present. Alkalinity is not detrimental to humans. High alkalinity levels (above 500 mg/L) may cause scale formation, the water may also have a distinctly flat, unpleasant taste. Moderately alkaline water (less than 350 mg/L), in combination with hardness, forms a layer of calcium or magnesium carbonate that tends to inhibit corrosion of metal piping. Many public water utilities employ this practice to reduce pipe corrosion and to increase the useful life of the water distribution system. Alkalinity Concentration less than 100 ppm are desirable for domestic water supplies (www.idph.state.il.us/envhealth/pdf/Drinkingwater.pdf).

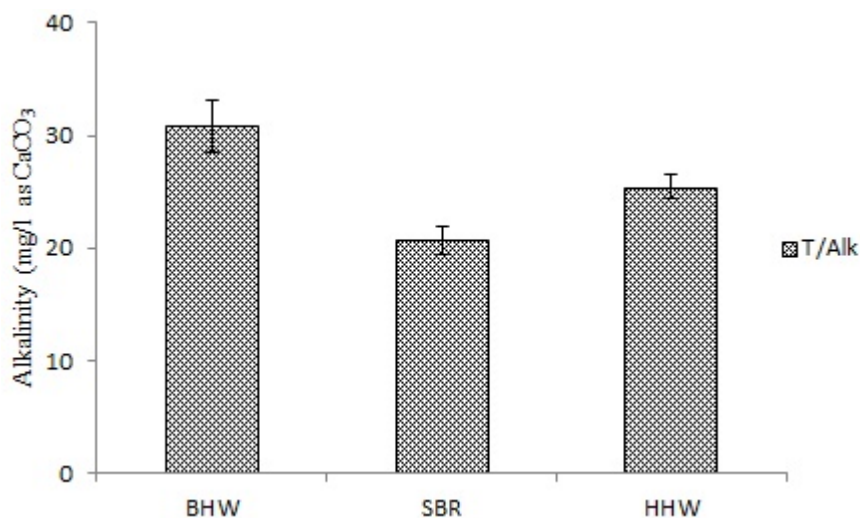


Figure 4.5: Occurrence of total alkalinity in water samples

BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples

4.1.6 pH

The mean pH values of the water samples ranged from 6.74 ± 0.10 to 7.06 ± 0.03 as illustrated in Figure 4.6. The pH levels were within WHO/GSA optimum limits of

between 6.5 and 8.5. Low pH levels are objectionable because of the corrosive effect on metal pipes and fixtures. Low pH can cause leaching of lead from solder used at joints of Cu pipes in older homes and of lead from brass plumbing fixtures. Metallic taste is frequently associated with low pH water. High pH levels decrease the effectiveness of disinfection by chlorination, thereby requiring the use of additional chlorine or longer contact times. The pH values greater than 8.5 could be a recipe for super saturation and enhance the precipitation of carbonate from the water.

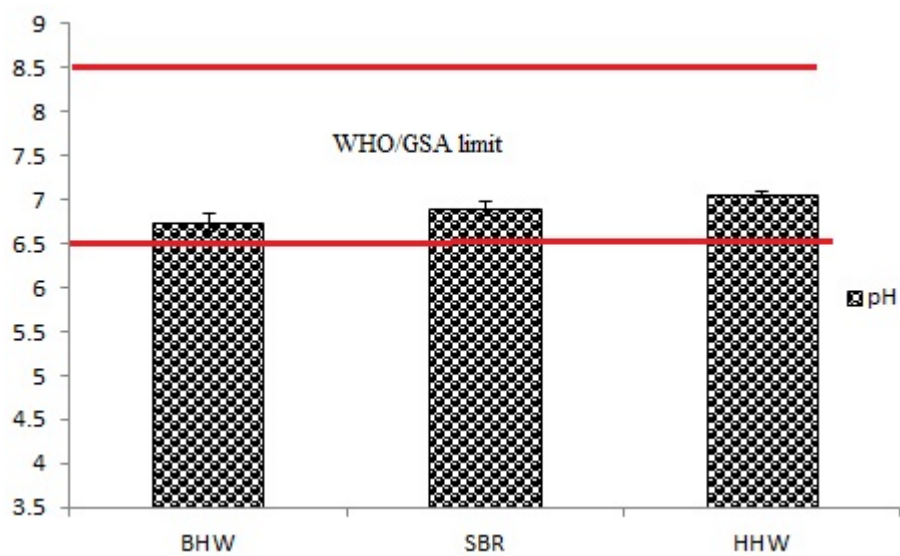


Figure 4.6: Level of pH in the water samples

BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples

4.1.7 Electrical Conductivity (EC)

Mean conductivity values of the samples ranged from $132.07 \pm 4.01 \mu\text{S}/\text{cm}$ to $149.79 \pm 3.00 \mu\text{S}/\text{cm}$ as shown in Figure 4.7. Electrical Conductivity is directly related to the salt content of the water. Hence, a higher conductivity indicates a higher salt concentration of the water (Hach, 2000). Whilst there is little direct health risk

associated with this parameter, high values are associated with poor taste and hence customer dissatisfaction and complaints.

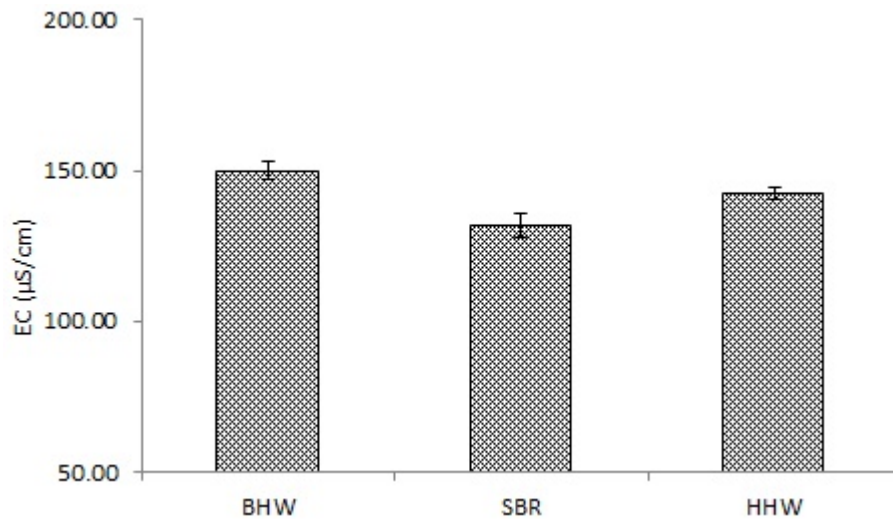


Figure 4.7: Electrical conductivity of the water samples

BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples

4.1.8 Colour

The mean colour recorded for the water sample ranged between 6.00 ± 0.67 Hz and 13.00 ± 3.80 Hz (Figure 4.8). While colour itself is not usually objectionable from the standpoint of health, its presence is aesthetically objectionable. The high mean colour value recorded for the Suame reservoir water samples might be due to; suspended materials present in the source water may have settled out in the storage facility and accumulation of sediments in the reservoir.

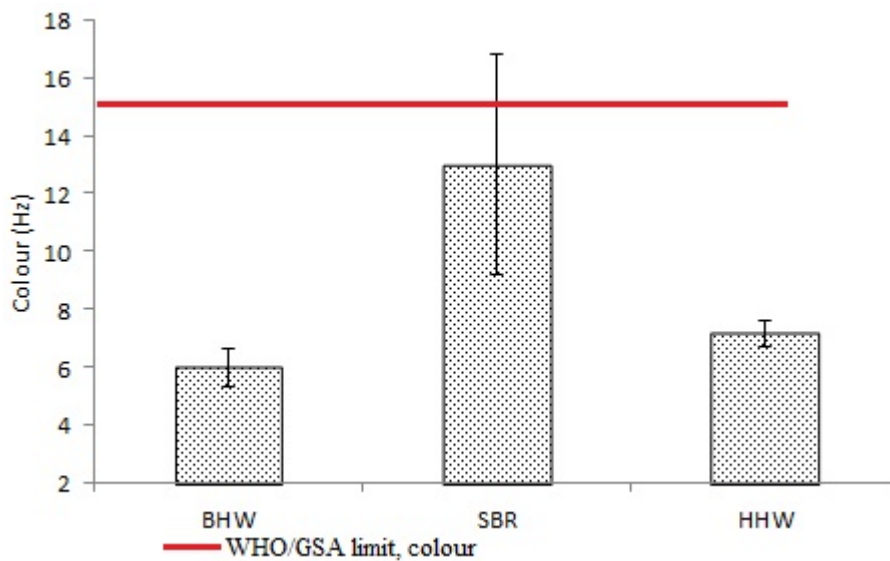


Figure 4.8: Level of colour in the water samples

BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples

4.1.9 Concentration of cations in the water samples

The mean total iron and Mn concentrations obtained for the water samples ranged between 0.092 ± 0.020 - 0.134 ± 0.020 mg/L and 0.009 ± 0.000 - 0.044 ± 0.002 mg/L respectively. The mean total iron and Mn levels were within WHO/GSA permissible level as illustrated in Figure 4.9. Although iron and manganese are essential trace nutrients; some people who drink water with iron levels well above the recommended upper limit of 0.3 mg/L could develop deposits of iron in a number of organs of the body (haemochromatosis) (Shelton and Scibilia, 2005). At levels above 0.2 mg/L and 0.1 mg/L for iron and manganese respectively they may cause aesthetic problems such as offensive taste, appearance and staining (WHO, 2006). The manganese is less common in the water samples as illustrated in Figure 4.9. This could be due to the fact that the raw water contains higher iron content because of the higher relative abundance of iron (5.4%) in comparison to manganese (0.1%) in average soils. This

could also be due to contribution to iron from iron corrosion products resulting from tuberculation in the pipe walls.

Metals like Calcium (Ca) and Magnesium (Mg) (shown in Figure 4.10) are essential elements needed by human body while Ca is used in teeth and bone formation; it also plays an important role in neuromuscular extractability, and for good functioning of the myocardial system, heart and muscle contractibility and also for blood coagulability (Frantisek K, 2003). Calcium and magnesium are important contributors to water hardness. When water is heated, they break down and precipitate out of solution, forming scale and although, maximum limits have not been established, magnesium concentration greater than 125 mg/L may have a laxative effect on some people (Orewole *et al.*, 2007). The low mean values of Ca^{2+} and Mg^{2+} obtained from the water samples could be due to the fact that the Ca^{2+} and Mg^{2+} content of the raw water is low.

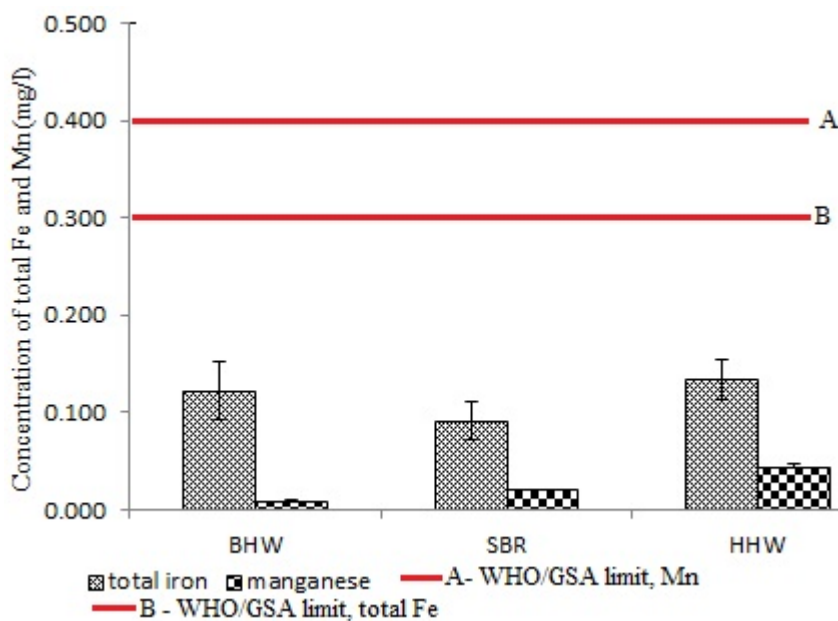


Figure 4.9: Total iron and manganese concentration of the water samples

BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples

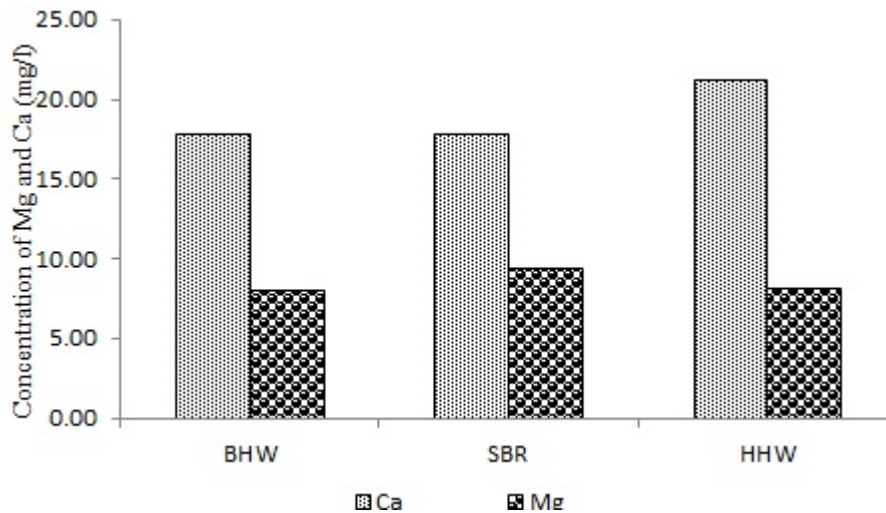


Figure 4.10: Concentration of Ca and Mg in the water samples

BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples

4.1.10 Nitrate-Nitrogen (NO_3-N) and Ammonia

The mean concentration of ammonia in all the water samples was 0 mg/L. The mean nitrate-nitrogen in the investigated water samples ranged between 0.81 ± 0.2 - 1.14 ± 0.18 mg/L (Figure 4.11) which was within the WHO/GSA guidelines of 10 mg/L. Nitrate may be transformed to nitrite in the human digestive system a condition normally occurring in infants. The nitrite ion oxidizes iron in the haemoglobin of the red blood cells to form methemoglobin, which lacks the oxygen-carrying ability of haemoglobin. This creates the condition known as methemoglobinemia (commonly referred to as “blue baby syndrome”), in which blood lacks the ability to carry sufficient oxygen to the individual body cells causing the veins and skin to appear blue. Infants under 6 months of age and older persons with genetically impaired enzyme systems are unable to reduce toxic methemoglobin to oxyhaemoglobin. Therefore, ingestion of nitrate can be fatal in a susceptible population groups (Runyan, 2002 and Kempster *et al*, 1997).

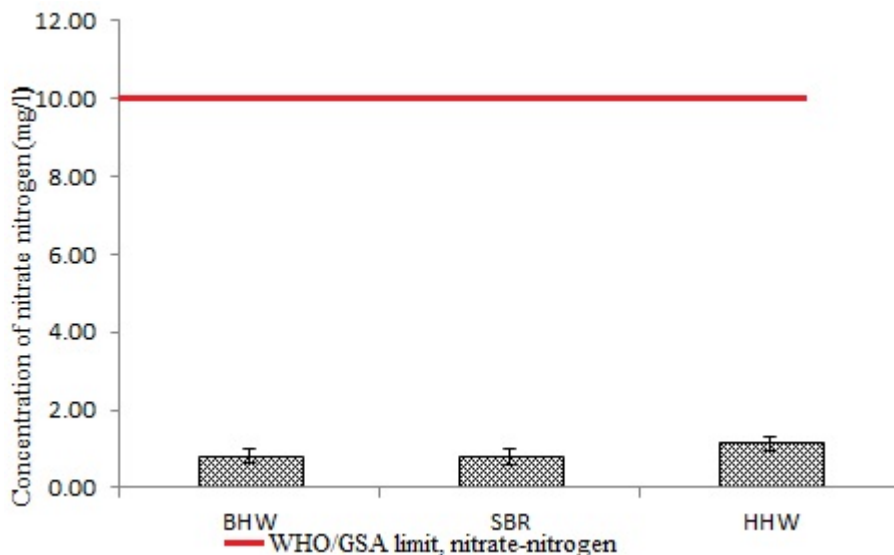


Figure 4.11: Occurrence of NO₃-N in water samples

BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples

4.1.11 Microbial content and Residual Chlorine level

The quality of the sampled waters did not pass the microbial tests as the occurrence of *E.coli* and other Coliform especially *salmonella* did not satisfy the WHO/GSA standards of 0 cfu/100 mL as shown in Figure 4.12. It is noteworthy however, that some faecal pathogens, including many viruses and protozoa, may be more resistant to treatment by chlorine than the indicator bacteria. The presence of coliform bacteria in water for domestic purpose has health implications, since consumption of unwholesome water affects human health in diverse ways (Hellard *et al*, 2001 and Mintz *et al*, 1995). The presence of coliform bacteria in the headworks water most probably is due to ineffective disinfection. Therefore the chlorination of drinking water must be improved and monitored more carefully. According WHO (2008) for effective disinfection, there should be a residual concentration of free chlorine of ≥ 0.5 mg/L after at least 30 min contact time at pH < 8.0. A chlorine residual should

be maintained throughout the distribution system. At the point of delivery, the minimum residual concentration of free chlorine should be 0.2 mg/L. Mean residual chlorine values of 0.51 ± 0.170 mg/L, 0.04 ± 0.017 mg/L and 0.01 ± 0.005 mg/L were recorded in the water from Barekese headwork (BHW), Suame Barekese reservoir (SBR), and household water (HHW) respectively (Figure 4.13). The difference in residual chlorine concentration between the headworks, Suame reservoir and households might be due to the utilization of the chlorine to disinfect intruded foreign materials or that pipe work has a high oxidant demand due to growth of bacteria. According to Norton *et al.*, 2003 and Digiano *et al.*, 2005 reactions involving corrosion products in cast iron pipes affect the chlorine decay rate in distribution systems, increasing the demand of chlorine residual and promoting microbiological activity.

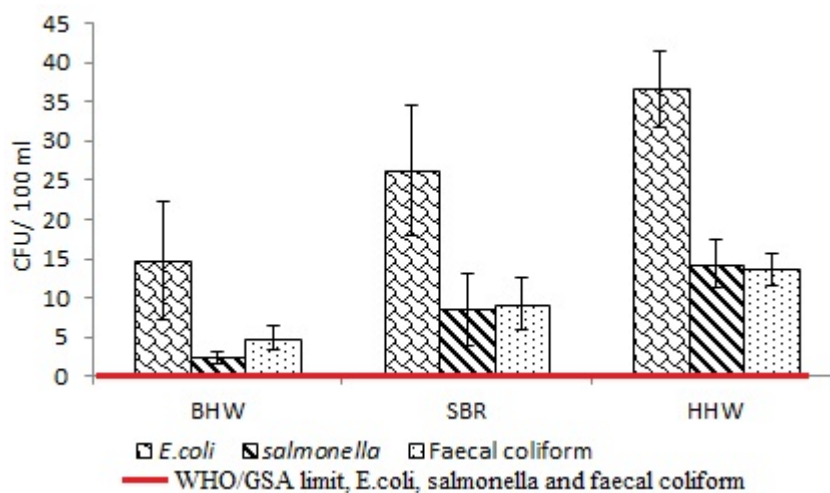


Figure 4.12: Occurrence of *E. coli*, *salmonella* and faecal coliform in water samples
 BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples.

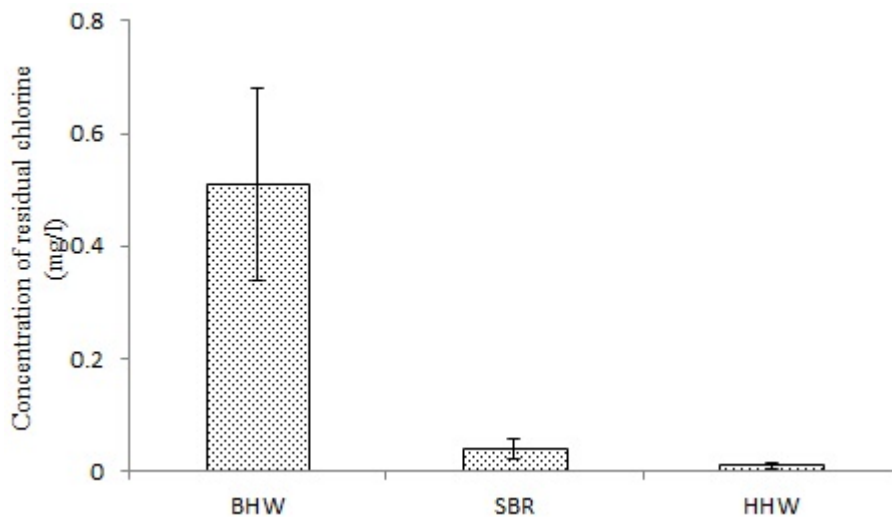


Figure 4.13: Occurrence of residual chlorine in water samples

BHW-Barekese headworks water samples, SBR- Suame Barekese reservoir water samples, HHW- Households water samples

4.2 Customer Perception Survey

A subjective performance assessment of GUWL water quality was carried out using a customer perception survey. The assessment of GUWL water quality from the point of view of the customers was conducted to add another perspective to the objective (laboratory and field test) assessment and highlight specific problems.

4.2.1 Perception on Physical properties of tap water and water usage

This part sought to assess customers' perception of the physical appearance of the water. Customers were asked the questions see appendices 1

Figure 4.14 shows 86%, 80% and 84% of the consumers were satisfied with the taste, colour and smell of the water respectively. As shown in Figure 4.15, 50% of the consumers confessed that they had sediment in their water upon storage.

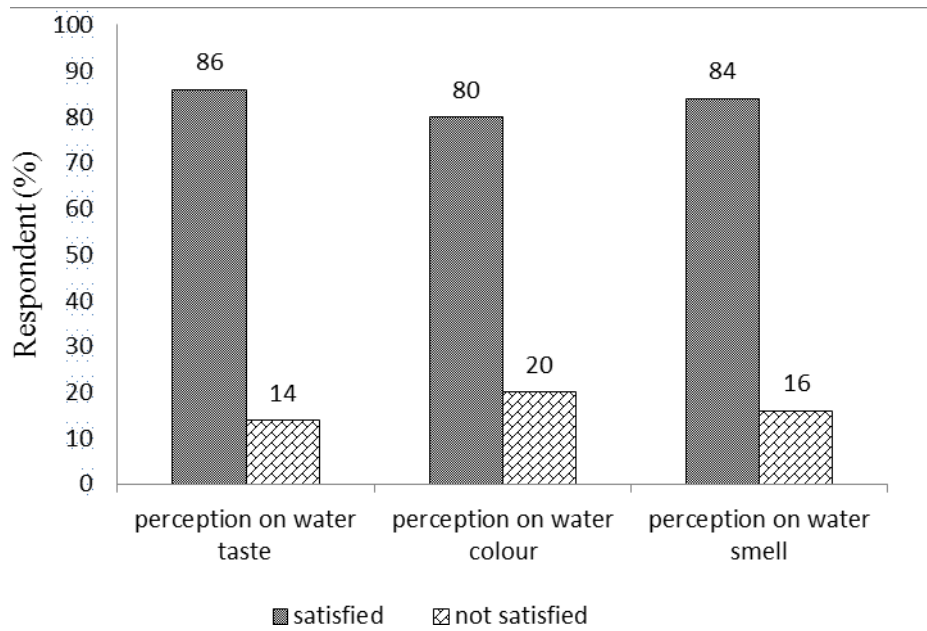


Figure 4.14: Consumer Perception on Colour, Taste and Smell of Water

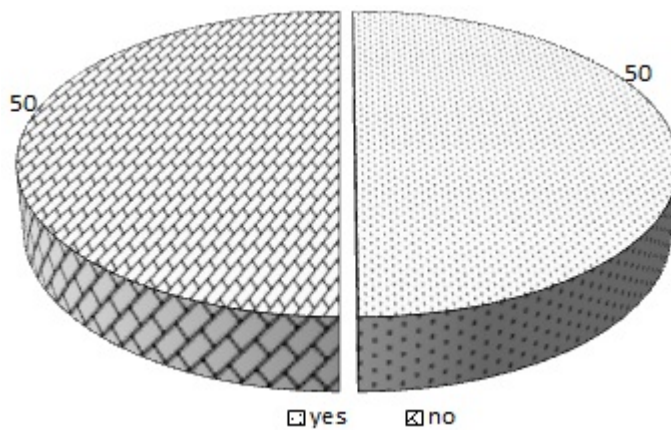


Figure 4.15: Sediment Content of Water

Figure 4.16 shows the percentage of respondents who used their water for drinking and cooking. Ninety (90%) of the respondents use their water for drinking while 10% of the respondents do not drink their water. All the respondents use their water for cooking.

Out of the 45 respondents (i.e. the 90% mentioned) who use water from Ghana Urban Water Limited (GUWL) for drinking, it is only approximately 34% of them who

depend solely on GUWL water. The remaining 66% use it alternatively with either “sachet” or bottled water (see Figure 4.17).

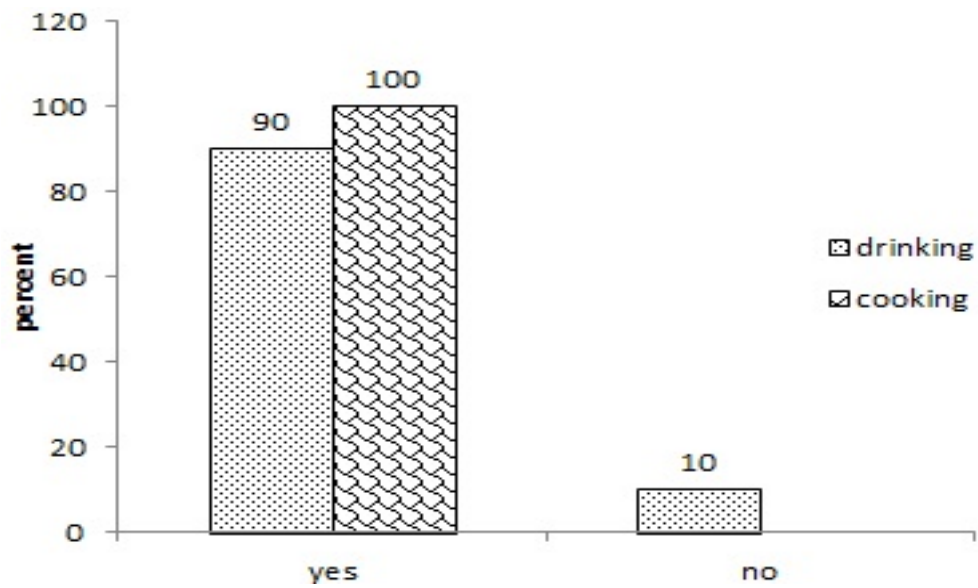


Figure 4.16: water usage

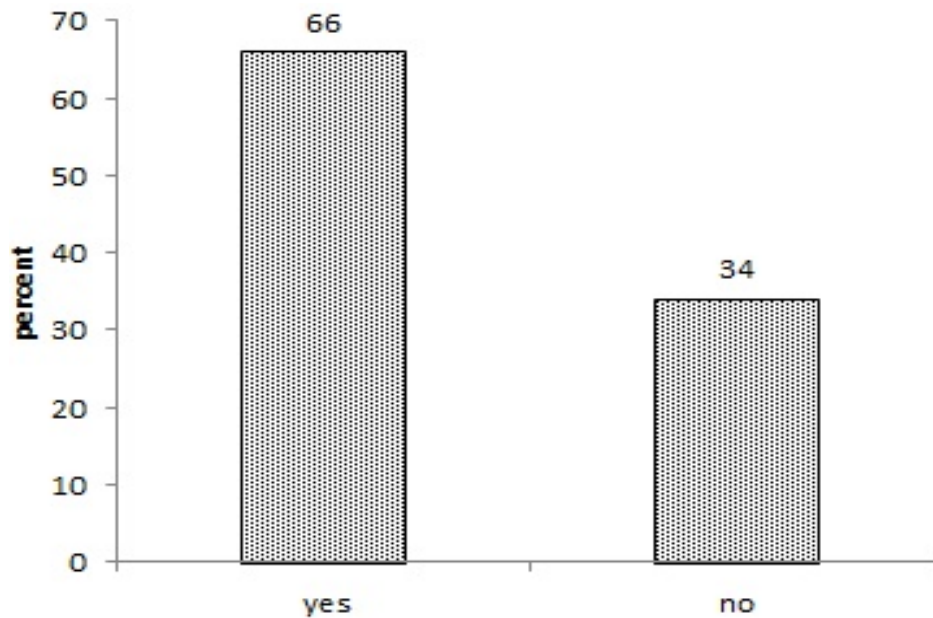


Figure 4.17: drinking of alternate water source

Statistical evidence (see Appendices 2.a, b, c) proved that respondents' perception of the water taste, smell and colour affected their choice of the water for drinking.

Approximately 3%, 5% and 5% of the respondents who were satisfied with the colour, taste and smell of the water respectively were not drinking it (Table 4.2). They explained that although they had no empirical proof that the water supplied by Ghana Urban Water Limited (GUWL) was unwholesome, they had doubts about its quality; doubts which they said were aroused by the dubious quality of water received immediately on resumption of supply after interruptions. It is noteworthy to state that these people were patronizing bottled water and not bagged water. Their preference for the bottled water over the bagged water is due to warnings from Food and Drugs Board (FDB) that some of the bagged water does not meet safety standards. Approximately 60%, 57% and 63% of the respondents who were not satisfied with the colour, taste and smell respectively of the water supplied by GUWL were drinking it (Table 4.3). Those were the respondents who appreciated the fact that problem with the aesthetic quality of drinking water do not necessarily mean it contains contaminants with potentially adverse health effects. To them the fact that GUWL applies disinfectant to their water provides them with some assurance that their water might be free from microbial infection. The same of which they cannot say for most of the bagged water sold on the streets or in shops.

Statistical evidence (see Appendices 3.e, f, g, h) showed that the usage of the water for cooking among the respondents was not influenced by their perception about the aesthetic appearance of the water. This was so because they were all aware that cooking water kills all the microbes it might contain.

Fifty percent (50%) of the customers complained about sediments in their water. For this reason, some of the consumers store their water and allow suspended solids to settle before usage. This was the reason why their usage of water for drinking was independent of sediment content (see appendices 1.d). Sediment can be resuspended

because of surges in flow, and sediment is a potential cause of water quality deterioration by contributing to the water's chlorine demand.

Though eighty percent (80%) of the customers were impressed with the colour of the water, they revealed that the water colour mostly looked brownish after any form of service interruption. The GUWL main distribution pipes are old metal pipes (60 years or more) that have received little or no replacement since the construction of the whole water supply system in Kumasi. For this reason, corrosion or rust of the main distribution pipes could have accounted for the brownish colour of the water as witnessed by consumers after service interruption. Internal corrosion also increases the consumption of disinfectant residual, development of large tubercles (collections of material that may include scale, algae, and bacteria) inside the pipes, reducing water-carrying capacity and water pressure which in turn creates deposits that are undesirable in terms of maintaining high microbial quality (LeChevallier *et al.*, 1993).

The laboratory analysis confirmed the presence of microbes in the supplied water at Adum. The presence of coliform bacteria in water for domestic purpose has health implications, since consumption of unwholesome water affects human health in diverse ways.

Table 4.2: Satisfaction with physical appearance of water and usage for drinking

Physical appearance of water	Usage for drinking		Total
	Yes	No	
Colour	39	1	40
Taste	41	2	43
Smell	40	2	42

Table 4.3: Non satisfaction with physical appearance of water and usage for drinking

Physical appearance of water	Usage for drinking		Total
	Yes	No	
Colour	6	4	10
Taste	4	3	7
Smell	5	3	8

4.2.2 *Handling of Leakages*

Out of the 50 customers interviewed, 5 respondents had reported about leakages to GUWL. All of them said the leakages were not attended to promptly (Figure 4.18).

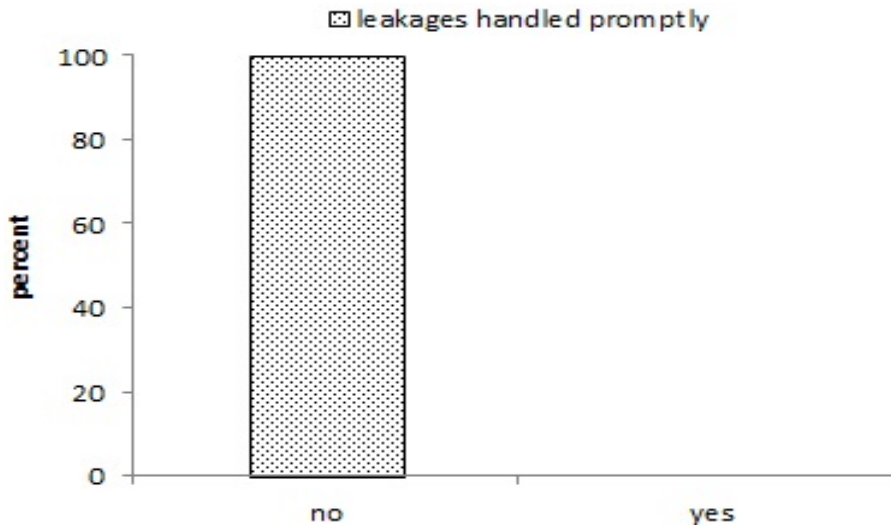


Figure 4.18: Handling of leakages

4.2.3 Intermittent water supply

All the respondents interviewed said their water flow was intermittent as illustrated in

Figure 4.19

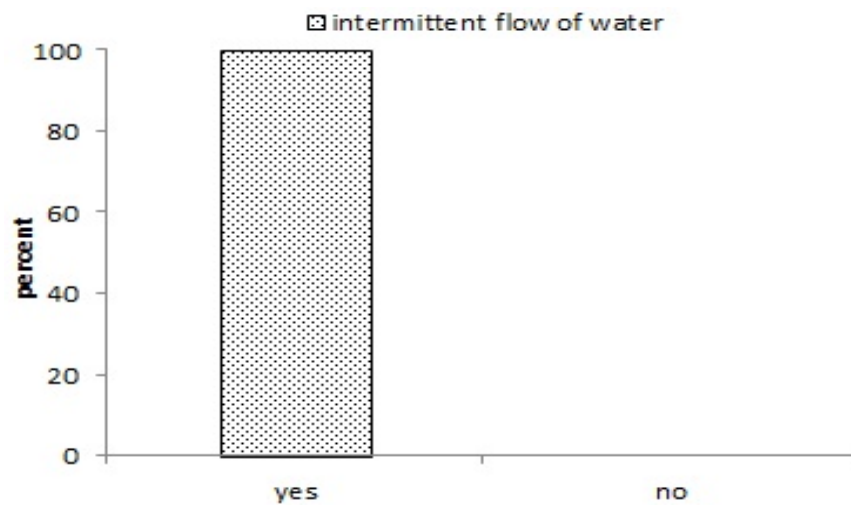


Figure 4.19: Intermittent water supply

Contaminated water can be introduced into the distribution system through the leakages that are not handled promptly. Intermittent supply of water can cause pressure drops which can allow contaminated water into pipe lines through reverse siphoning.

CHAPTER FIVE

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the results obtained and analysis made, the following conclusions have been arrived at:

- The mean concentrations of the physicochemical parameters assayed for at the headworks and households were within the permissible limits of World Health Organisation (WHO) and Ghana Standard Authority (GSA)
- Coliform bacteria were detected in the water samples from the headwork and households. The presence of coliform bacteria in the water samples is of concern from a health perspective. With detection of coliform bacteria in the water samples, the health of consumers might have been compromised through incidences of water related diseases and efforts must be made to remediate the occurrence.
- Consumers' complaint about the colour of the water supplied immediately after interruption. This could be due to deposits and encrustations in the network. These deposits get aroused when pumping is resumed after interruption.
- Customers were satisfied with the quality of water supply delivery. Majority (86%) of the consumers had no problem with the taste of the water, 80% and 84% also indicated having no problem with the colour and smell of the water supplied. However, 50% of the respondents indicated the presence of sediment in their water.

- Customers' perception of the water taste, smell and colour affected their choice of the water for drinking but it was independent of the sediment content.
- Usage of the water for cooking among the consumers was not influenced by their perception about the aesthetic appearance of the water.

5.2 Recommendations

Based on the results obtained and conclusions drawn from the study, the following have been recommended

- Chlorination should be monitored more carefully to ensure residual chlorine level of at least 0.5 mg/L at the headworks.
- The chlorination contact time of 30 minutes recommended by WHO should be implemented at the headworks to ensure effective disinfection.
- Boosting of chlorination at Suame is highly recommended.
- Regular cleaning of water mains by flushing should be implemented to get rid of sediments in the distribution system.
- Additional clear well should be provided to allow for regular cleaning without disrupting the continuous water production as particulates built-up in the clear well can protect microorganisms from the effects of disinfection and can stimulate bacterial growth in the clear well.
- Replacement of the ageing distribution pipes should be done.
- Leakages in the distribution lines should be quickly attended to.

- More of such study should be conducted in all remaining areas in Kumasi and replicated in the other major cities or urban centres in Ghana in order to evaluate on a wider scale the quality of water supplied to consumers.

REFERENCES

- African Development Bank: Infrastructure development in Africa. African Development Report, Oxford University Press, New York, 1999
- Al-Ruwaih, F. M., Alhumoud, J.M. and Al-Mutairi, S. M. (2010). "Quality of potable water in Kuwait". *Am. J. of Environmental Sciences* 6 (3): 260-267.
- Anadu, E. C., Harding, A. K. (2000). "Risk perception and bottled water use". *J. Am. Water Works Assoc.* November, 82–92.
- Auslander, B. A., Langlois, P. H., (1993). "Toronto tap water: perception of its quality and use of alternatives". *Can. J. Public Health* 84 (2), 99–102.
- AWWA. American Water Works Association. (1995). Problem organisms in water: identification and treatment. AWWA M 7. Denver, CO.
- AWWA (1999). Water Quality and Treatment: A handbook of community water supplies, 5th ed. Letterman, R. D. (Ed) McGraw-Hill, Inc., New York.
- AWWA (2000). Water Distribution Systems Handbook. McGraw-Hill, Inc., New York, NY.
- AWWA and EES, Inc. (2002). New or repaired water mains. <http://www.epa.gov/safewater/tcr/pdf/maincontam.pdf> [Accessed August 20, 2010].
- Berger, P. S., Clark, R. M., and Reasoner, D. J. (1993). Water, Drinking. In: Encyclopaedia of Microbiology. Vol. 4:385-398.
- Beuhler, M. D., Foust, D. A., and Mann, R. W. (1994). "Monitoring to Identify Causative Factors of Degradation of Water Quality: What to Look For," *Proceedings of the 1994 Annual AWWA Conference*, American Water Works Association; Denver, CO.
- Biswas, A. K. (1997). Water resources: environmental planning, management, and development. McGraw- Hill: New York.
- Blackburn, B. G., Craun, G. F., Yoder, J. S., Hill, V., Calderon, R. L., Chen, N., Lee, S. H., Levy, D. A., and Beach, M. J. (2004). Surveillance for waterborne-

disease outbreaks associated with drinking water—United States, 2001–2002. *MMWR* 53(SS-8):23-45.

Block, J. V., Gauthier, V., Rosin, C., Mathieu, L., Portal, J. M., Chaix, P., and Gatel, D. (1996). "Characterization of the Loose Deposits in Drinking Water Distribution Systems," In *Proceeding of the AWWA Distribution System Symposium.*, American Water Works Association, Denver, CO,

Blokhuis, M., Brouwer, R., Hulscher, R. and Thiadens, A. (2005). "Feasibility Study Barekese Water Expansion Project, Kumasi, Ghana", Draft Report Project Number - 9R3818, 73 pp.

Borchardt, J. A. and Walton, G. (1971). Water Quality and Treatment, 3rd ed. McGraw-Hill, Inc. New York, pp. 4-167.

Bouchard, D. C., Williams, M. K., and Surampalli, R. Y. (1992). "Nitrate contamination of groundwater: sources and potential health effects". *J. Amer. Water Works Assoc.* 84(9):84–90.

Boulos, P. F., Grayman, W. M., Bowcock, R. W., Clapp, J. W., Rossman, L. A., Clark, R. M., Deininger, R. A., and Dhingra, A. K. (1996). "Hydraulic mixing and free chlorine residual in reservoirs". *J. Amer. Water Works Assoc.* 88(7):48–59.

Burlingame, G. A., and Anselme, C. (1995). Distribution system tastes and odours. In: *Advances in Taste-and-Odour Treatment and Control*, pp. 281-320. AWWARF/Lyonnaise des Eaux publication. American Water Works Association Research Foundation, Denver, CO.

Burlingame, G. A., and Brock, G. L. (1985). "Water Quality Deterioration in Treated-Water Storage Tanks," in *Proceedings of the 1985 Annual AWWA Conference*, American Water Works Association, Denver, CO.

Characklis, W. G., and Marshall, K. S. (1990). Biofilms: a basis for an interdisciplinary approach. pp. 3-15. In: *Biofilms*. Characklis, WG, and KS Marshall (eds.). J. Wiley and Sons. New York, NY.

Clark, R. M., Grayman, W. M., Good rich, J. A., Deininger, R. A., and Hess, A. F. (1991). "Field testing distribution water quality models". *J. Amer. Water Works Assoc.* 83(7):67–75.

- Clark, R. M., Geldreich, E. E., Fox, K. R., Rice, E. W., Johnson, C. H., Goodrich, J. A., Barnick, J. A., and Abdesaken, F. (1996). Tracking a *Salmonella* serovar *typhimurium* outbreak in Gideon, Missouri: role of contaminant propagation modelling. *Journal of Water Supply Research and Technology-Aqua*. 45:171–183.
- Cobbina, S. J., Nyame, F., Hodgson, I. O. A. (2009). “Assessment of the Quality of Piped Water Supplied to Households in Western Accra”. *Journal of Applied Science and Tecnology*, Vol. 14, Nos. 1 & 2, 2009, pp. 44-49
- Cohn, P. D., Cox, M., and Berger, P. S. (1999). Health and aesthetic aspects of water quality, Chapter 2. pp. 2.1-2.86. In: *Water Quality and Treatment* (5th ed.). Letterman, R. D (ed.). McGraw- Hill, Inc. New York, NY.
- Conant, J. (2005). Sanitation and cleanliness for a healthy environment. Hesperian Foundation. Berkeley, pp. 4-48.
- Craun, G. F. (1986). *Waterborne diseases in the United States*. CRC Press Inc., Boca Raton, Florida, USA.
- Craun, G. F. and Calderon, R. L. (1999). Waterborne disease outbreaks: their causes, problems, and challenges to treatment barriers. AWWA manual M-48: waterborne pathogens. American Water Works Association, Denver, USA.
- Crozes, G. F., and Cushing, R. S. (2000). Evaluating biological regrowth in distribution systems. AWWARF. Denver, CO.
- Digiano, F.; Zhang, W., Pipe Section Reactor to Evaluate Chlorine–Wall Reaction. *Journal American Water Works Association* **2005**, 97, (1), 74-85.
- Falkenmark, M., Lundqvist, J. and Widstrand, C. (1990). Coping with water scarcity
- Frantisek, K., (2003). Health Significance of Drinking water with Ca and Mg. National Institute of Public Health.
- Geldreich, E. E. (1996). *Microbial Quality of Water Supply in Distribution Systems*. Lewis Publishers. Boca Raton, FL.
- Geldreich, E. E., Fox, K. R., Goodrich, J. A., Rice, E. W., Clark, R. M., Swerdlow, D. L. (1992). Searching for a water supply connection in the Cabool, Missouri disease outbreak of *Escherichia coli* 0157:H7. *Water Research* 26(8):1127–1137.

- Geldreich, E. E., and Rice, E. W. (1987). “Occurrence, significance, and detection of *Klebsiella* in water systems”. *Journal of the American Water Works Association*, 79(5), 74.
- Haas, C. N., Chitluru, R. B., Gupta, M., Pipes, W. O., and Burlingame, G. A. (1998). Development of disinfection guidelines for the installation and replacement of water mains. Denver, CO: AWWARF.
- Hach Company (2000). *Water Analysis Handbook*. 2nd. ed. Hach Company, Loveland, Colorado, USA. P.829.
- Hannoun, I. A., and Boulos, P. F. (1997). “Optimizing distribution storage water quality: a hydrodynamic approach”. *Journal of Applied Mathematical Modeling* 21(8):495–502.
- Hellard M. E, Sinclair, M. I, Forbes, A. B. and Fairley, C. K. (2001). Randomized, blinded, controlled trial investigating the gastrointestinal health effects of drinking water quality. *Environmental Health Perspectives*. Vol 109, No. 8. pp 773-776
- Horsburgh, C. R. (1991). “*Mycobacterium avium* complex infection in the acquired immunodeficiency syndrome”. *New England Journal of Medicine* 324:1332–1338.
- Hunter, P. R. (1997). *Water-borne Disease: Epidemiology and Ecology*. Chichester: John Wiley & Sons. Implications of biomass strategy for communities and policies”, *Water Resources Development*. 6(1), pp. 29 – 43.
- Hutton, G. and Haller, L. (2004). *Water, Sanitation and Health. Protection of Human Environment*.
- James. And Lamb. (1985). *Water quality and its control*.
- Jardine, C. G., Gibson, N., Hrudehy, S. E. (1999). Detection of odour and health risk perception of drinking water. *Water Sci. Technol.* 40 (6), 91–98.
- Kempster, P. L, Van Vliet, H. R., Kuhn, A. (1997) The Need for Guideline to Bridge the Gap between Ideal Drinking Water Quality and Quality which is racticably Available and Acceptable. *Water SA*.;23(2):163–7.

- Kirmeyer, G. J, Friedman, M., Martel, K. D., Howe, D., LeChevallier, M., Abbaszadegan, M., Karim, M., Funk, J., and Harbour, J. (2001). Pathogen intrusion into the distribution system. AWWARF. Denver, CO.
- Kruis, F. (2007). Environmental chemistry- Selected methods for water quality analysis. UNESCO Laboratory Manual, pp. 1-116
- Kuma, J. S., Owusu, R. O., Gawu, Simon K. Y. (2010). ‘Evaluating the Water Supply System in Kumasi, Ghana.’ *European Journal of Scientific Research*. Vol.40 No.4 (2010), pp.506-514
- Lahlou, Z. M. (2002). Water quality in distribution systems. Tech Brief. A national drinking water clearinghouse fact sheet. West Virginia University
- Larson, B. A., Gnedenko, E. D. (1999). Avoiding health risks from drinking water in Moscow: an empirical analysis. *Environ. Dev. Econ.* 4 (4), 565–581.
- LeChevallier, M. W. (1999a). Biofilms in drinking water distribution systems: significance and control, Chapter 10. pp. 206-219. In: *Identifying future drinking water contaminants*. National Academy Press. Washington, DC.
- LeChevallier, M. W., *et al.* (1993). Examining the relationship between iron corrosion and the disinfection of biofilm bacteria. *Journal of the American Water Works Association*, 85:111–123.
- Levallois, P., Grondin, J., Gingras, S. (1999). Evaluation of consumer attitudes on taste and tap water alternatives in Quebec. *Water Sci. Technol.* 40 (6), 135–139.
- Levi, Y. (2004). ‘Minimizing potential for changes in microbial quality of treated water’ In: Ainsworth, R. (eds.) *Safe Piped Water: Managing Microbial Water Quality in Piped Distribution Systems*. London: IWA Publishing, UK.
- Lu W, Kiene, L., Levi Y., (1998). Chlorine demand of biofilms in water distribution systems. *Water Research*, 33(3):827–835.
- Martin, R. S., Gates, W. H., Tobin, R. S *et al.* (1982). ‘Factors affecting coliform bacteria growth in distribution systems’. *Journal of the America Water Works Association* 74, 34-37.

- McIntosh, A. C. (2003), *Asian Water Supplies: Reaching the Urban Poor*, Asian Development Bank and International Water Association, London, U. K.
- Meintz, E. D., Reiff, F. M. and Tauxe, R. V. (1995). Safe water treatment and storage in the home: A practical new strategy to prevent water borne diseases. IMA. Vol. 237, no. 12
- Ministry of works and housing, National water Policy, August 2005.
- Montgomery, M., Bartram, J. and Elimelech, M. (2009). Increasing Functional Sustainability of Water and Sanitation Supplies in Rural Sub-Saharan Africa. *Environmental Engineering Sciences*, Vol.26, No.50, pp 1017-1023
- Nash, H., McCall, G. J. H. (Eds.), (1995). *Groundwater Quality*. 17th Special Report. Chapman and Hall, London United Kingdom.
- Nightingale, S. D., Byrd, L. T., Southern, P. M., Jockusch, J. D., Cal, S. X., and Wynne, B. A. (1992). “*Mycobacterium avium-intracellulare* complex bacteremia in human immunodeficiency virus positive patients”. *Journal of Infectious Disease* 165:1082–1085.
- Norton, C.; LeChevallier, M.; Falkinham III, J., Survival of *Mycobacterium avium* in a model distribution system. *Water Research* **2003**, 38, 1457-1466.
- Nyarko, K. B. (2007). Drinking water sector in Ghana: Drivers for performance. PhD thesis UNESCO-IHE.
- Orewole, O. M., Makinde, O. W., Odekalu, K. O., Shittu, K. A., (2007). “Chemical examination of piped water supply of Ile-Ife in southwest Nigeria”. *Iran J. Environ. Health. Sci. Eng., Vol. 4, No. 1, pp. 51-56.*
- Powell, J. C., Hallam, N. B., West, J. R., Forster, C. F., Simms, J. (2000). Factors which control bulk chlorine decay rates. *Water Res.* 34 (1), 117–126.
- Pruss-Ustun, A., Bos, R., Gore, F., and Bartram, J. (2008). *Safe Water, Better Health: Cost, Benefit and Sustainability of Interventions to Protect and Promote Health*. World Health Organization, Geneva.
- Ray, B. T. (1995). Environmental Engineering. PWS Publishing Company. Boston, pp. 4-222-343.

- Rodriguez, M. J., Se´rodes, J. B. (2001). Spatial and temporal evolution of trihalomethanes in three water distribution systems. *Water Res.* 35 (6), 1572–1586.
- Runyan, C. (2002). Nitrate in Drinking Water Guide M-114, New Mexico State University, Cooperative Extension Service College of Agriculture and Home Economics. <http://www.cahe.nmsu.edu/pubs/m/m-114.pdf>. [Accessed September 6, 2010].
- Schindler, D. W. (1990). Effects of climate warming on lakes of the central Boreal Forest, *Science*, Vol. 250, pp. 967-970.
- Shelton, T. B and Scibilia, S. E., (2005). *Interpreting Drinking Water Quality Analysis What do the numbers mean?* 6th Edition
- Sulemanova, M., (2002), Access to water in developing countries. Page 178.
- Suthar, S., Chhimpa, V., Singh, S. (2008). Bacterial contamination in drinking water: A case study in rural areas of northern Rajasthan, India. *Environ Monit Assess*; doi:10.1007/s10661-008-0611-0.
- Trussell, R. R. (1999). ‘‘Safeguarding distribution system integrity’’. *J. Amer. Water Works Assoc.* 91(1):46-54.
- UKWIR (2000). Toolboxes for maintaining and improving drinking water quality. Report 00/DW/03/11, Section 8, Toolbox for pH, UK Water Industry Research Limited, London.
- UNCED (1992). Protection of the Quality and Supply of Freshwater Resources: Application of Integrated Approaches to the Development, Management and Use of Water Resources. The United Nations Conference on Environment and Development. Chapter 18, Agenda 21
- UNESCO (1997). The United Nations education, scientific and cultural organization .Down to the last drop.
- USEPA (1992). Control of biofilm growth in drinking water distribution systems. EPA/625/R-92/001. Washington, DC.

- USEPA (1995). Draft Turbidity criteria document, Office of research, development, and office of drinking water. Washington D.C, pp. 13-253.
- USEPA (2002a). Finished water storage facilities. American Water Works Association and Economic Engineering Services, Inc., Voorhees, NJ
<http://www.epa.gov/safewater/tcr/pdf/storage.pdf>. [Accessed on August 12, 2005].
- USEPA (2002b). Health risks from microbial growth and biofilms in drinking water distribution systems. <http://www.epa.gov/safewater/tcr/pdf/biofilms.pdf>. [Accessed on July 23, 2010]. Washington, DC: EPA
- USEPA (2005). Small Drinking Water Systems: State of Industry and Treatment Technologies to Meet the State Drinking Water Act Requirements. EPA-600-X-05-021. Cincinnati, Ohio.
- USEPA, (2008) Water Quality in Small Community Distribution Systems: A Reference Guide for Operators. EPA-600-R-08-039. Cincinnati, Ohio.
- Van der Wende, E., and Characklis, W. G. (1990). Biofilms in potable water distribution systems. Chapter 12 In: Drinking water microbiology. G. A. McFeters (ed.). New York: Springer-Verlag.
- Walch, M. (1992). Corrosion, microbial. pp. 585-591. In: Encyclopaedia of Microbiology. (Vol. 1). Lederberg, J. (ed.). Academic Press. New York, NY.
- WHO (1993). Guidelines for drinking water quality. Second edition, Vol. 1, world health organization Geneva
- WHO (1998). Guidelines for drinking water quality. Health criteria and other supporting information. Geneva: World Health Organization. Vol. 2.
- WHO (2003). Emerging issues in water and infectious disease. Geneva.
- WHO (2006). Guidelines for drinking-water quality: Incorporating first addendum. 3rd ed. WHO. Vol.1.
- WHO (2008). Guidelines for drinking-water quality. incorporating 1st and 2nd addenda, Vol.1, Recommendations. – 3rd ed. Geneva

WHO/UNICEF, (2000), *Global Water Supply and Sanitation Assessment 2000 Report*, WHO/UNICEF, Geneva/New York.

WHO/UNICEF (2005). Rapid assessment of drinking-water quality in the Hashemite kingdom of Jordan: country report of the pilot project implementation.

WHO/UNICEF (2008). Progress on Drinking Water and Sanitation : Special Focus on Sanitation. New York: WHO-UNICEF, Geneva.

Wilczak, A., Jacangelo, J. G., Marcinko, J. P., Odell, L. H., Kirmeyer, G. J., and Wolfe, R. L. (1996). Occurrence of nitrification in chloraminated distribution systems. *Jour. AWWA*, 88(7):74-85.

(WSDH) Washington State Department of Health (2004). Water sampling: What we test for and why.

www.afdb.org, [20th November, 2009].

www.arch.columbia.edu/studio/spring2003/UP/Accra [accessed August 20, 2011]

www.idph.state.il.us/envhealth/pdf/Drinkingwater.pdf [20th November 2010].

www.undp.org, [15th October, 2010].

www.who.org, [20th November 2010].

APPENDICES

APPENDIX 1 – QUESTIONNAIRE

PUBLIC PERCEPTION SURVEY

The following questionnaire has been designed to solicit relevant information in furtherance of the objectives of a research document looking into water quality deterioration in piped water and its effect on usage and customers' perception in Adum-Kumasi, Ghana.

The researcher is a student of the Kwame Nkrumah University of Science and Technology. The information you provide will be treated as confidential and will be used only for academic purposes. Thank you for your time and cooperation.

Date of Interview

1. Is your household connected to GUWL network? Yes [..] No []
2. Is your water stored in a container for use? Yes [..] No []
3. Does the water you fetch have sediment upon storage? Yes [..] No []

Kindly tick against each of the following uses of water with respect to supply from GUWL.

4. Drinking Yes [..] No []
5. Cooking Yes [..] No []
6. Do you drink any other water source? Yes [..] No []
7. If yes, specify Sachet [] bottled [] others specify
8. What is your impression about the physical water quality?
 - (a) Taste? Satisfied [] Not satisfied []
 - (b) Smell? Satisfied [] Not satisfied []
 - (c) Colour? Satisfied [] Not satisfied []

9. Have you ever made a complaint to GUWL about leakage in a distribution line?

Yes [] No []

10. If yes, was it attended to promptly? Yes [..] No []

11. Is your water flow intermittent? Yes [..] No []

Managers Survey (Checklist)

These are questions which guided the researcher in the interview conducted with the managers of the water service delivery.

1. Meet the General managers to introduce yourself.
2. Find out how the distribution of the water is conducted.
4. Ask for maps of distribution districts.
5. Age of distribution lines in the study area
5. What is your average customer level of satisfaction with overall quality of water in their household?

APPENDIX 2 – NULL HYPOTHESIS

(a) Table Showing Influence of water taste on usage of water for drinking

		perception on water taste		Total
		satisfied	not satisfied	
usage of water for drinking	yes	41	4	45
	no	2	3	5
Total		43	7	50

Chi-Square Tests

	Value	df	P value
Pearson Chi-Square	9.764	1	0.002

H_0 : Null hypothesis

H_1 : Alternate hypothesis

H_0 : Drinking of GUWL water is independent of the customers' perception of the water taste.

H_1 : Drinking of GUWL water is not independent of the customers' perception of the water taste.

at α (level of significance) = 0.05

Since $X_0^2 = 9.764 > X_{0.05, 1}^2 = 3.84$, we reject the null hypothesis and conclude that drinking water supplied by GUWL is not independent of customers' perception of the water taste.

(b) Table Showing Influence of water smell on usage of water for drinking

	perception on water smell		Total
	satisfied	not satisfied	
house use for drinking yes	40	5	45
no	2	3	5
Total	42	8	50

Chi-Square Tests

	Value	df	P value
Pearson Chi-Square	8.003	1	0.005

H_0 : Drinking of GUWL water is independent of the customers' perception of the water smell.

H_1 : Drinking of GUWL water is not independent of the customers' perception of the water smell.

at $\alpha = 0.05$

Since $X_0^2 = 8.003 > X_{0.05, 1}^2 = 3.84$, we reject the null hypothesis and conclude that drinking water supplied by GUWL is not dependent of customers' perception of the water smell.

(c) Table showing Effect of customers' perception of water colour on usage for drinking

		perception on water colour		Total
		satisfied	not satisfied	
house use for drinking	yes	39	6	45
	no	1	4	5
Total		40	10	50

Chi-Square Tests

	Value	df	P value
Pearson Chi-Square	12.500	1	0.000

H_0 : Drinking of GUWL water is independent of the customers' perception of the water colour.

H_1 : Drinking of GUWL water is not independent of the customers' perception of the water colour.

at $\alpha = 0.05$

Since $X_0^2 = 12.500 > X_{0.05, 1}^2 = 3.84$, we reject the null hypothesis and conclude that drinking water supplied by GUWL is dependent of the customers perception of the water colour.

(d) Table 5: Effect of customers' perception of water sediment content on usage for drinking

	sediments in water		Total
	yes	no	
house use for drinking yes	22	23	45
no	3	2	5
Total	25	25	50

Chi-Square Tests

	Value	df	P value
Pearson Chi-Square	0.222	1	0.637

H_0 : Drinking of GUWL water is independent of the customers' perception of the water colour.

H_1 : Drinking of GUWL water is not independent of customers' perception of the water sediment content.

at $\alpha = 0.05$

Since $X_0^2 = 0.222 < X_{0.05,1}^2 = 3.84$, we fail to reject the null hypothesis and conclude that customers' drinking of water supplied by GUWL is independent of their perception of the water sediment content.

(e) Table Showing effect of sediment content of water on its usage for cooking

	sediments in water		Total
	yes	no	
house use for cooking yes	25	25	50
Total	25	25	50

Table shows that customers' usage of the water for cooking is independent of the sediment content of the water.

(f) Table Showing usage of water for cooking on perception of water colour

	perception on water colour		Total
	satisfied	not satisfied	
house use for cooking yes	30	20	50
Total	30	20	50

Table shows that customers' usage of the water for cooking is independent of their perception of the water colour

(g) Table Showing Influence of usage of water for cooking on perception of water smell

	perception on water smell		Total
	satisfied	not satisfied	
house use for cooking yes	42	8	50
Total	42	8	50

Table shows that customers' usage of the water for cooking is independent of their perception of the water smell

(h) Table Cross tabulation of usage of water for cooking on perception of water taste

	perception on water taste		Total
	satisfied	not satisfied	
house use for cooking yes	43	7	50
Total	43	7	50

Table shows that customers' usage of the water for cooking is independent of their perception of the water taste.