SCHOOL OF PUBLIC HEALTH
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ASSESSING THE QUALITY OF HOUSEHOLD DRINKING WATER IN SELECTED COMMUNITIES IN THE AKUAPEM SOUTH DISTRICT

BY

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DECLARATION

I, KOFI ASARE LARTEY hereby declare that apart from references to other people`s works which have been duly acknowledged, this research work is a result of my own independent work under supervision. I further declare that this work has not been submitted for any other degree in this institution or any other elsewhere.

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(ACADEMIC SUPERVISOR)

DEDICATION

This work is dedicated to my family for their love, motivation, support and encouragement throughout the course of my studies and to my dad Mr. O. K. Lartey of blessed memory.

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ABSTRACT

Background: Water quality is a growing concern throughout the developing world as sources of drinking water are constantly under threat from contamination. This exposes the general population to various hazardous contaminants in water. Water quality assessment, especially household stored water is therefore necessary to ensure that clean and safe drinking water is delivered and sustained to reduce drastically, the disease burden and other public health issues that are associated with the use of unsafe water.

Objective: The main objective of this study was to ascertain the quality of drinking water that is stored in vessels or containers, among households in selected rural communities in the Akuapem South District.

Method: This was a cross-sectional study involving five (5) towns which were selected based on their strategic location, total number of households in the community and the prevailing socio-economic activities. A multi-stage sampling technique was used to enroll participants for the study. A household list from the 2010 population and housing census was used as sample frame. From the complete list of households, respondents were selected by the systematic random technique for questionnaire administration to elicit demographic information, water supply sources, behaviours relating to household water treatment methods, sanitation and hygiene practices, including hand washing practices. A total of 215 questionnaires were administered in addition to 30 household stored water samples collected for quality analysis.

Results: Eighty per cent (80%) of household water tested in the study area contained *E. coli* and all (100%) of the water samples collected, contained thermotolerant coliform (TTC) bacteria. The mean *E. coli* (77.7±99.2 cfu/100mL) and TTC (232.8±115.8

cfu/100mL) in household water samples were higher compared to the WHO guideline for drinking water quality (GDWQ). However, the mean physico-chemical characteristics of household water samples were all within the WHO limits, although 50% of water samples in the study area failed the pH test. The main water source used by households in the study area was borehole, accounting for 81.4%, followed by protected well (14%) and 3.7% piped water. Just a small proportion (0.9%) reported collecting water from streams, rivers and ponds as the main source of drinking water. Water source, time spent for collection, sanitation and hygiene influenced water quality, even though the association was not statistically significant.

Conclusion: The findings of this study indicate that household stored water is heavily contaminated with bacteria mostly due to poor water handling and insanitary conditions under which water is stored, although majority of households have access to an improved source of water (borehole). Furthermore, the findings showed that water, sanitation and hygiene practices are predictive of faecal contamination in household stored water, as confirmed in the water quality test. Putting everything in context, these findings emphasize the requirement for interventions in households, including water treatment, safe water handling, improved storage and proper hand hygiene to guarantee safe drinking water, among households.

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ACRONYMS AND ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
AfDB	African Development Bank
APHA	American Public Health Association
AWWA	American Water Works Association
COD	Chemical Oxygen Demand
EC	Electrical Conductivity
GDWQ	Guidelines for Drinking Water Quality
GLSS 6	Ghana Living Standards Survey 6
GSS	Ghana Statistical Service
GWCL	Ghana Water Company Limited
MDGs	Millennium Development Goals
MF	Membrane Filtration
MWRWH	Ministry of Water Resources Works and Housing
OECD	Organization for Economic Co-operation and Development
STATA	Statistics and Data
TDS	Total Dissolved Solids
TTC	Thermotolerant Coliform
UNICEF	United Nations International Children Emergency Fund
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
WASH	Water, Sanitation and Hygiene
WEF	Water Environment Federation
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Water is one of the most significant normal assets for human work and survival on earth. It is required in almost all human activities and is a most important factor in health, safety and riches (Arbués *et al*., 2003; Boateng and Adams, 2013). It is utilized for various purposes which include drinking, preparation of food, sanitation and hygiene. Access to safe drinking water is fundamental to human improvement as well as a right. Lack of access to safe drinking water sources, poor sanitation and cleanliness, compromise general wellbeing (WHO/UNICEF, 2014; World Health Organization, 2016).

Drinking water is obtained from ground, rain and surface water sources. Since water is in a nonstop dissemination on earth, the quality shifts all around with the seasons, soil and other substances through which it passes. Chemical substances are available in drinking water and its sources as a result of various anthropogenic factors including inappropriate waste transfer, open defecation, indiscriminate dumping of garbage, poor agrarian practices and compound spills from industrial activities, which contaminate water and make it difficult to identify and isolate single contaminants (WHO, 2017).

Since the clearness of water is not the sole determinant of its safety or wholesomeness, it is important to determine the quality of water in order to reduce the levels of hazardous contaminants before consumption. This is because the hazardous substances in water often lead to dangerous diseases when consumed (WHO and UNICEF, 2012; World Health Organization, 2017). The World Health Organization (WHO) consequently sets guidelines for drinking water quality (GDWQ) which underscore the need to adopt an increasingly comprehensive strategy to assess all the compounds in water for safe levels and not to concentrate only on one source when detailing national policy (WHO, 2017). Information from WHO show that 87% of the total populace, and 84% of the populace living in low income countries currently use drinking water from more secure and improved sources (WHO, 2010). In sub-Saharan Africa, only 60% of the populace obtain their drinking water from improved sources (WHO, 2010). The principal sources nonetheless, in most African countries however, are from boreholes, deep and shallow wells, pipe borne, dug-outs, rivers and streams, most of which are generally of low quality. Water quality is a developing worry for all developing nations (UNICEF, 2012) as drinking water sources are continually being degraded by hazardous contaminants. Drinking water that has been contaminated with faecal matter is a significant contributor to water borne ailments like diarrhea and dysentery, attributed to causing the death of numerous children world-wide every year (UNICEF, 2012; Curtis *et al*., 2012).

Ghana faces a challenge in accessing clean drinking water and sufficient sanitation facilities resulting in 70% of ailments. Consequently, those in the low-income brackets are the most affected (AfDB/OECD, 2007; Boateng and Adams, 2013). A good number of households transport and store water in their houses because they do not have piped water connected to their premises. Under these circumstances, water may become contaminated when ingested (UNICEF, 2012), but households are compelled to utilize this unhygienic and less dependable water, leading to water-borne diseases, and end up paying more for hazardous water than the rich does for clean water (AfDB/OECD, 2007).

Water quality testing is in this way, fundamental within households in rural areas (WHO and UNICEF, 2012), especially when access, availability and quantity still remains a major challenge. When the supply of water is efficiently protected, regulated and managed, water quality can be guaranteed. This however requires the identification of critical points of contamination where quality may be compromised. It is against this backdrop that water quality evaluation and constant monitoring must be carried out particularly, in rural areas to guarantee that individuals obtain perfect, protected and good quality drinking water (UNICEF, 2010).

1.2 Problem Statement

Findings by WHO demonstrate that 844 million individuals still need essential drinking water supply (United Nations Children Fund and World Health Organization, 2017), making individuals travel long journeys to obtain water. Additionally, close to 80 percent of the total populace live in territories with high water scarcity problems, mostly in developing nations with about 3.4 billion individuals at greatest risk (UNEP, 2012). Despite the fact that the drinking water target of the Millennium Development Goals (MDGs) were significantly met in 2010, significant disparities still exist among rural and urban dwellers. UNEP (2012) reports that while 19 percent of inhabitants living in rural areas needed access to improved water in 2010, it was only 4 percent in urban areas. Water quality appraisal which is one proven approach to ensure the wholesomeness of drinking water is typically consigned to the background in these areas primarily because of the difficulties in accessing water. A study conducted in South Africa by Odiyo and Makungo (2012), showed inadmissible degrees of *E. coli*, nitrates, fluorides, and total dissolved solids (TDS) in borehole water. There is also sufficient proof to demonstrate that high levels of these substances in drinking water have adverse implications on the wellbeing of the populace (Edusei, 2012; World Health Organization, 2006).

Drilling records in the eastern region of Ghana demonstrates that 20 – 30% of borehole water have iron and manganese levels well in excess of the WHO requirement, making the water unwholesome for consumption (Kosinski *et al*., 2016; Kulinkina *et al*., 2017). Despite the availability of boreholes, supplemented by treated piped water from the Ghana Water Company Limited (GWCL), there are issues with accessibility and availability, as a result of the unreliable nature of supply (Asiedu, 2014). Households are therefore compelled to travel long distances to collect water to be stored in vessels or containers for use. Since the water is mostly stored in plastic drums, metal tanks and barrels over long periods, it may become contaminated by harmful bacteria and hazardous chemicals due to poor water handling practices, poor sanitation and poor waste management practices, leading to water borne diseases such as dysentery, cholera, typhoid etc., when consumed. It is in view of these factors that this study seeks to assess the quality of stored household drinking water in the Akuapem South District, to help formulate policies for improvement of the quality of stored drinking water in the district.

1.3 Justification

In spite of the fact that the MDG Target 7C, to increase improved water coverage among individuals who do not utilize safe water has been accomplished, a few people still remain unserved. The marker used to quantify access to an improved water source, does not really ensure that water is protected upon accumulation (World Health Organization, 2017). An ongoing investigation that considered the probability for source water degradation projected that 1.8 billion individuals overall depend on a drinking water source that is faecally contaminated. The deterioration potential rises when households transport and store water in vessels, particularly when more than 263 million individuals walk more than 30 minutes including queuing, for each round trek to collect water. Additionally, 159 million people still accumulate drinking water openly from surface water sources, 58% of whom are found in sub-Saharan Africa (United Nations Children Fund and World Health Organization, 2017).

Household drinking water assessment especially in rural areas will help devise measures to decrease water deterioration during storage in the homes. Additionally, households will become enlightened on the need to properly handle, treat and store water hygienically to prevent recontamination. Finally, policy frameworks that will protect usable sources of water from degradation by anthropogenic activities can be formulated by local authorities and stakeholder groups, based on the outcome of the water assessment.

1.4 Conceptual Framework Narrative

The quality of drinking water depends on the physical, chemical and microbiological parameters as well as handling, transportation and storage. Suitability of water for various use also depend on the type and concentration of dissolved minerals (Mirribasi *et al*., 2008), and the level of contamination by hazardous environmental contaminants such as faecal matter, refuse, wastewater and heavy metals. Water bodies can be contaminated directly through insanitary conditions and poor hygienic practices including poor disposal of human and animal waste (UNICEF & WHO, 2019). Household stored water in particular, remains susceptible to contamination from a number of factors. Notable among these are water sources, accessibility and quantity of water used, inadequate sanitation facilities, poor hygiene practices especially, hand hygiene (UNICEF & WHO, 2019). Other sources of household water contamination include time spent for collection or distance to water source, presence of toilet in the house and distance to toilet facility, presence of animals in the house, storage duration, frequency of cleaning storage vessel, leakage of vessel, covering of vessel, water withdrawal methods, whether or not the water is stored in clean surroundings and the water treatment methods used (UNICEF & WHO, 2018), in addition to socio-economic challenges including income and education levels. A number of studies have shown that some of the factors mentioned above are significantly associated with the quality of household drinking water Trevett *et al*., (2004), Vankatesen *et al*., (2014), Duodu (2014), Asiedu (2014) and Boateng & Adam (2013). Drinking from such water sources may impact negatively on the health of people culminating in water-borne diseases like diarrhea, cholera, dysentery etc.

The conceptual framework diagram below explains the interactions among WASH practices, socio-economic activities and quality of stored household water:

1.4.1 Conceptual Framework

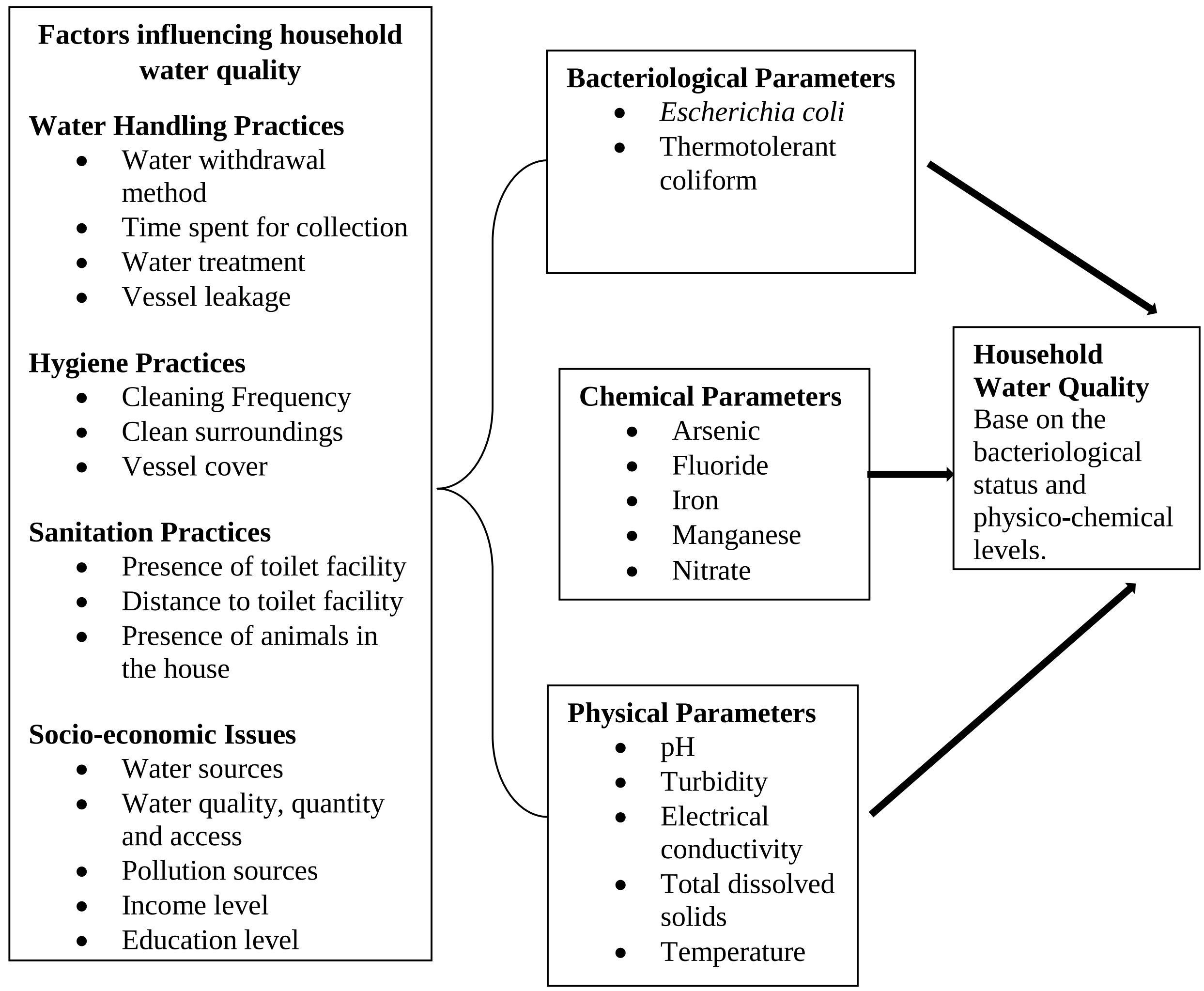


Figure 1: Conceptual Framework for Household Water Quality Assessment.

1.5 Research Questions

- What are the sources of stored household drinking water for people in Akuapem South District?
- What are the levels of microbial contaminants in stored household drinking water in the district?
- What are the concentrations of physico-chemical parameters in stored household drinking water in the district?
- Which water, sanitation and hygiene practices are adopted by households in the district?

1.6 Objectives of the study

1.6.1 Main Objective

- To determine the quality of stored household drinking water in selected rural communities in the Akuapem South District.

1.6.2 Specific Objectives

- To identify the source(s) of stored household drinking water for the selected rural communities.
- To assess the levels of microbial contaminants in household drinking water.
- To quantify the levels of some selected physico-chemical parameters in stored household drinking water.
- To assess water, sanitation and hygiene practices of households in the district.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Water Resources Potential

The two main water sources in Ghana are groundwater and surface water. The Volta, South-western and Coastal rivers make up the surface water resources. These three main river schemes cover 70%, 22% and 8% respectively of the entire territory of Ghana. There is also Lake Bosomtwi which is the only natural freshwater, believed to have been created by a meteorite fall and stretches 50 km^2 in the forest zone (MWRWH, 2015).

2.1.1 Surface Water Resources

The typical Ghanaian is not so enthused about harvesting rain, but it provides a substantial amount of water that can be utilized by households, especially during the wet season of May, June, July and August (Akumiah, 2007). With the right innovations, harvesting rainwater can make water available and easily accessible for use by both households and institutions alike, especially when the country's average annual overflow is estimated to be about forty (40) billion cubic metres (MWRWH, 2015).

2.1.2 Groundwater Resources

In terms of sustainability, there is enough evidence to prove that ground water has numerous advantages than surface water. It is progressively reliable and consistent even in the dry season, provided it is not sited close to areas where human activities may introduce contaminants at the source particularly in shallow aquifers. The major drawback with regards to groundwater is the high levels of saline, mainly in the coastal areas of the country which render it unsuitable for drinking without treatment, although it can be used for other domestic purposes (MWRWH, 2015).

2.2 Water Access and Safety

Water supply is a basic requirement to poverty reduction, improvement of health and the prosperity of children and adults alike. Various nations resolved to reduce by 2015, the number of individuals without feasible access to safe drinking water and essential sanitation in the MDGs. While numerous endeavors have brought about the realization of this commitment, the safety of many water supplies still remains in doubt. The UNICEF and WHO Joint Monitoring Program (JMP) for Water Supply and Sanitation reports biennially on advancement towards accomplishing this objective, in light of insights with respect to access to water innovations which may be improved or unimproved (UNICEF and WHO, 2012).

The classification was based on the idea that improved innovations, due to the structure and predominance of construction would adequately protect the source from outside degradation, particularly by faeces, and hence likely to offer water of better quality and lessen public health risks, despite the fact that it was perceived this would not generally be the situation (UNICEF and WHO, 2012). As it were, the JMP appraisals do not provide data on real drinking water quality, in spite of the fact that it has recently started information gathering on household water quality in some developing nations (UNICEF and WHO, 2019).

2.3 Water Quality and Health

Water hugely affects the wellbeing of people both as a medium for reducing diseases and a channel in which certain disease-causing life forms might be transmitted. The adverse effect of water on wellbeing originates from ingesting water that contains pathogenic life forms or poisonous chemicals and utilizing small quantity of water leading to poor individual and domestic cleanliness (WHO and UNICEF, 2012). The danger of contracting waterborne disease increases with the degree of degradation by pathogenic microorganisms. The relationship is anyway not that simple and relies upon variables, including, high dose and host weakness for example.

Drinking water is just a single route for the transmission of such pathogens, however a few species might be transmitted from individual to individual, or by means of consuming foods which have been contaminated (WHO and UNICEF, 2012). As a rule, poor personal cleanliness may lead to the transmission of pathogenic agents in water stored for later use (Curtis, *et al*., 2000; Julian, *et al*., 2013). Poor cleanliness behaviours arise from the utilization of little water quantities, resulting in water-washed diseases. To prevent the spread of diseases, discarding human excreta safely is paramount. Subsequently, diarrhoeal morbidity and mortality is reduced by enhancing the quality and accessibility of water, excreta transfer and overall individual and environmental cleanliness (WHO and UNICEF, 2012).

Monitoring the quality of water is key in decreasing the potential for erratic pandemics, as debased distribution of water is the main conduit for bulk spread of pathogenic agents in human populations. Be that as it may, water quality may not be the priority in controlling endemic sicknesses. Various preventive measures may have significant effect on various groups and at various occasions in the same community, yet water quality will consistently be central (WHO and UNICEF, 2012).

2.3.1 Chemical Contaminants and Water Quality

Connections between the levels of chemicals and human wellbeing are likewise outstanding. Chemical compounds occurring naturally in water are seldomly hazardous to health, in spite of the fact that nitrates in water may introduce a genuine health danger to infants. Some other chemicals, (for example, arsenic and fluoride) can cause protracted medical conditions, during active ingestion spanning significant duration (WHO, 2017). Chemicals, for example, manganese and iron, which might be available in water, will probably only colour the drinking water and stain washed apparels, without any immediate health consequences. This may however, influence how people perceive the water, which may prompt consumers to reject the water source for one that does not have these unacceptable properties. Analysis of the bacteriological levels in water is the most significant water quality parameter due to its public health importance, because pathogenic organisms initiate the onset of disease and can multiply awfully fast to invade the host. The quality of groundwater is largely accepted to be better than surface water. Treatment of surface water is therefore important to ensure it is fit for the intended purpose (WHO, 2011).

2.3.2 Physical Nature and Water Quality

Under circumstances where water is transported over long distances, recontamination of water with pathogens is a regular occurrence (Jessoe, 2013) and is progressively perceived as a significant public health problem. Evaluating the quality of water is accordingly significant among households just as at sources and networked supplies (WHO and UNICEF, 2012). The quality of water must therefore, not be judged in light of visual assessment, (taste and smell) alone, as it may be misleading. Water that look or smell disagreeable might be wholesome to drink, while clear scentless water may rather contain harmful pollutants that may be inimical to peoples' health. Target procedures for water appraisal are in this manner fundamental.

2.4 Factors Influencing Household Water Quality

2.4.1 Water source, Transportation and Handling

The source where water is collected (improved, unimproved or surface) affects the quality. The UNICEF & WHO (2019) report on the progress in drinking water, sanitation and hygiene indicates that a number of household surveys that incorporated direct testing of drinking water for faecal contamination at source and point of use had high *E. coli* levels, especially at the household level. When the origin of water supply is located outside one's premises, the risk of contamination is high, highlighting the need for safe handling, storage and treatment. Available data indicate that the proportion of households using very high risk drinking water in Ghana as at 2012-2013, increased by about 66.7% between collection and point of use (UNICEF & WHO, 2019).

2.4.2 Time Spent for Collection and Distance

There are several studies which suggest that the farther a water source is from households the higher the risk of contamination. Results from a study conducted by Boateng, Adams, & Tia-Adjei, (2013), show that the quality of household water decreases with increasing distance, compared to shorter distance (OR=0.48; $p<0.05$). Additionally, UNICEF & WHO (2012), also confirms that the quality of water deteriorates when households have to make a round trip of more than 30 minutes including queuing to collect water.

2.4.3 Hand Washing Practices

Regular hand washing is an important way of reducing bacterial load and breaking the chain of disease transmission. The hand is always in contact with fomites which may be habouring disease causing pathogens. Without regular hand washing practices, these pathogens may be transferred into stored water resulting in contamination. As at 2017, data on hand hygiene showed that more than half of the population in 19 countries out of 78 had no hand wash facility at all in their houses with an additional 10 million across 30 countries also without any hand was facility (UNICEF & WHO, 2019).

2.4.4 Toilet Distance

Stored water risk being contaminated with on-site sanitation facility especially, when they are close. This risk increases with the type of toilet facility in use. An enhanced sanitation facility however, decreases the danger of faecal-oral pathogen transmission. In situations where households must walk long distances to attend to nature’s call, open defecation is common in addition to improper disposal of human excreta. These factors have the potential of contaminating household water and increase the risk of disease transmission (UNICEF & WHO, 2019).

2.4.5 Presence of Toilet

Insufficient toilet facilities and method of excreta disposal are closely related to diarrhoeal diseases, which aggravate malnutrition and remains a leading cause of childhood deaths, in addition to parasitic infections like soil transmitted worms. While access to a hygienic toilet facility is vital in reducing the distribution of disease-causing organisms, it is likewise crucial to ensure the safe disposal of human excreta produced (UNICEF & WHO, 2019). The importance of safe management of human excreta to public health can therefore not be over-emphasized. A study conducted by Boateng, Adams & Tia-Adjei (2013), showed that although not significant, the proportion of households with good quality water was higher among respondents with toilet in the house compared to those who did not have.

2.4.6 Water Treatment

Treatment of water before drinking is essential in reducing the transmission of many waterborne pathogens thereby preventing waterborne diseases. The treatment method used also influences the efficiency of the removal of hazardous contaminants and improves the quality of water significantly. One study by Daniel (2015), showed that households who practiced water treatment had their stored water quality being marginally better than those who did not ($p=0.01$). It is instructive to note from this study that although peoples knowledge about water treatment method was associated with cleaner water at the point of collection ($p<0.01$), it was not the same with stored water. A study by Guo *et al*. (2017), on the other hand, indicates that there was no significant difference between people who reported treating their stored water and those who did not.

Furthermore, in areas where water treatment was reported, water quality was worse than areas where water treatment was not reported.

2.4.7 Vessel Cover

Although storage containers may be covered, studies have shown that lack of proper hand hygiene and unsafe water withdrawal could result in recontamination of stored household water. Water storage vessels that have cover or lid are less likely to be contaminated in contrast with those that are not covered or without lid. This is so because uncovered water storage vessels are prone to the introduction of dirt from the immediate surroundings as well as faecal contaminants from insanitary conditions.

2.4.8 Water Withdrawal

The method or means by which households withdraw water from storage vessels may result in contamination. Because majority of households do not have a tap or spigot fixed on their water storage vessels, water is usually withdrawn by means of a cup or other crude methods which have been linked with contamination in a number of studies. One of such studies by Guo *et al*. (2017) indicated that majority of respondents interviewed use unsafe methods such as cups, bowls or even hands to withdraw water from storage vessels, resulting in degradation of the water quality.

2.4.9 Presence of Animals

Waterborne transmission of a harmful strain of *E. coli* (O157) from animal origin has been associated and documented with outbreaks such as haemolytic uremic syndrome (HUS), particularly in drinking water and to a less significantly recreational water

(Dufour and Bartram, 2012). This raises concern about the contamination of water with animal excreta. Effler *et al*. (2001), in an outbreak study showed that cattle manure was the source of over 40,000 cases of waterborne diseases with the organism in Swaziland. Another study in Lancashire, UK by Wilson *et al.* (2008), established that 96.6% of human clinical infections with *Campylobacter jejuni* could be attributed to farm livestock.

2.4.10 Vessel Cleaning Frequency

Boateng, Adams, & Tia-Adjei, (2013), in a study revealed that there is no significant association between the frequency of cleaning water storage vessels and the quality of stored water, however, the duration of water storage was significantly associated with quality of household water (p=0.025).

2.5 Water, Sanitation and Hygiene and Water Contamination

The water, sanitation and hygiene behavior or practices of people influences the quality of household drinking water in diverse ways because of the high propensity of transferring harmful pathogens from unhygienic hands, utensils and surroundings into water (WHO, 2017). The water source, quantity, accessibility and availability as well as the type of sanitation facility and conditions under which water is stored including the duration, are key determinants in the contamination of household water (UNICEF & WHO, 2019; Boateng, Adams and Tia-Adjei, 2013). Hygiene embraces a range of behaviours that contribute to the sustenance of health and prevention of the spread of diseases. These include handwashing, food hygiene and menstrual hygiene management of girls within households all of which affect the quality of household water (UNICEF & WHO, 2019).

2.6 Water Quality Analysis

The health benefits of water does not rest only on adequacy, but also importantly on the quality (WHO and UNICEF, 2012). Consumption of water that is infected with disease-causing organisms or contaminated with hazardous chemicals or heavy metals leads to diseases including cholera, enteric dysentery and typhoid. Respiratory and cardiovascular diseases, skin cancer, liver enlargement, neurological disorders and foetal death may also be encountered in the long term (Jarup, 2003; Mahurpawar, 2015; Ali *et al*., 2017; Susko *et al*., 2017). Contaminated water may also mar the effectiveness of medical appliances and medications (WHO and UNICEF, 2012) and consequently, lead to poor healthcare delivery and adverse health outcomes. Drinking water quality for multipurpose use will therefore be assessed based on pH, turbidity, conductivity, total dissolved solids, iron, manganese, arsenic, fluoride, nitrate, *E. coli* and thermotolerant coliforms.

2.7 Microbial Parameters

The conventional function of indicator parameters in drinking water is a sign of fecal contamination and hence, health hazard (WHO and UNICEF, 2012). The novel microbial parameters were all bacteria that originated from fecal pollution. Fecal-oral ailment, may not be triggered just by enteric microbes yet may result from pathogens such as viruses or protozoa. Viruses and protozoa have diverse ecological conduct and survival qualities to bacteria, which implies that fecal bacteria may not be a satisfactory marker for their presence or otherwise. This is particularly valid for sanitized drinking water, as bacteria are exceptionally delicate to disinfectants, though viruses and parasites can be very resilient (WHO and UNICEF, 2012).

Therefore, the notion that the concentration of pointer organisms ought to be identified with the degree of fecal pollution and by suggestion to the quantity of pathogens and the rate of waterborne sickness cannot be maintained. Nevertheless, the thought behind the utilization of conventional fecal marker parameters, while not completely binding, is as yet functional and helpful today if the parameter is picked accurately (WHO and UNICEF, 2012). It is regularly utilized in observing drinking water at the tap and as it leaves the treatment works. Regardless of the weaknesses that have been perceived, numerous locales still use it to test for coliforms, with or without reciprocal testing for *E.coli* or thermotolerant coliforms. Despite the issues pertaining to pathogen testing, it is common practice to utilize pointer organisms, broadly bacteria, for the investigation of microbial nature of drinking water in light of the fact that most waterborne pathogens originate from faeces (WHO and UNICEF, 2012).

2.8 Indicator Bacteria

2.8.1 *Escherichia coli* and thermotolerant coliforms

Escherichia coli (*E. coli*) is the most widely utilized bacterial pointer or as a replacement, thermotolerant coliforms (TTC) may be used. Human and animal excreta contain a chunk of *E. coli* (mostly non-pathogenic), however there are few species that are pathogenic (for example *E. coli* O157:H7). There is some proof that *E. coli* can increase in nutrient-rich tropical soils, in spite of the fact that it is commonly perceived that this phenomenon is restricted. Much of the time, the indigenous microscopic organisms would out-contend the *E. coli* (WHO and UNICEF, 2012).

Numerous projects use TTC as a substitute for *E. coli*, in light of the fact that outcomes can be acquired rapidly and economically, although strictly speaking results from TTC counts are hypothetical for *E. coli*. TTCs are a group of coliform bacteria that thrive at 44 ºC and contain *E. coli* as well as other species that may have a natural source. In temperate regions it is estimated that around 95% of TTCs are *E. coli*, however in tropical regions it is proposed that this proportion might be essentially lower (WHO and UNICEF, 2012). This infers that caution must be exercised when interpreting the results of analysis, and highlights the requirement for other information accumulation techniques. TTC analysis can be performed utilizing a wide range of techniques, and results can be attained within 14-24 hours using relatively inexpensive methods.

2.8.2 Total Coliforms

A more extensive group of coliforms (frequently referred to as total coliforms) are once in a while incorporated in assessment programs. The total coliform group contains a wide range of coliform bacteria, including both fecal and environmental species. Total coliforms comprise organisms that endure and develop in soil and water conditions. They are therefore of no sanitary or public health significance in being used as a marker for faecal pathogen (WHO, 2011). Total coliform examination (at 37 °C as opposed to 44 °C) has frequently been utilized in water supplies that has been chlorinated, as they are anticipated to be absent as a result of their susceptibility to chlorine. Their occurrence in water, in this way, is taken to suggest that impurity has happened. In any case, the noteworthiness of total coliform existence in such water sources is likely to be constrained, as the larger part will originate from biofilm developing inside the conveyance framework. The health significance of bacterial regrowth stays questionable, yet is accepted to be irrelevant. Total coliform use is not prescribed in any supply of water which is not chlorinated as they are anticipated and so of no sanitary consequence (WHO and UNICEF, 2012).

2.9 Chemical Parameters

2.9.1 Arsenic (As) in Water

Arsenic has both metal and non-metal properties and so is classified as a metalloid, though it is often referred to as a metal (ASTDR, 2007). Drinking water sources may be contaminated with arsenic due to mineral depositions in rocks, pesticides containing arsenic compounds and unsafe and unregulated disposal of industrial waste into water bodies. Ingestion of arsenic in children may result in acute poisoning and death (Mahurpawar, 2015). At low levels arsenic can induce toxicity even at low levels of exposure due to their systemic toxicant nature (Jan *et al*., 2015). Concentrations in air and water in rural areas range from 1 – 4 ng/m^3 while in the cities it is estimated to be around 200 ng/m^3. The presence of arsenic in drinking water is a significant source of exposure to humans (Goyer *et al*., 2004). The limit allowed in drinking water by WHO is 0.01 mg/L (WHO, 2011b).

2.9.1.1 Health Effects of Arsenic

Exposure to arsenic in drinking water in the long term may lead to skin cancer, in addition to other skin disorders, including hyperkeratosis and changes in skin pigmentation. A study carried out by Jarup (2003), indicated a relationship between high exposure-response and cancer development. Deliberate arsenic ingestion in children has been shown to lead to poisoning, neuropathy which affect the skin dermatomes and eventual death (Mahurpawar, 2015). Arsenic exposure also induces liver enlargement (Ali *et al*., 2010) and foetal death in cases of pregnant women (Susko *et al*., 2017).

2.9.2 Iron (Fe) in Water

Natural fresh water resources such as rivers, springs and lakes through the process of weathering and leaching contain a significant amount of iron. It is an important nutrient for algae and other organisms in fresh water (WHO, 1996). Concentrations of iron in drinking water are ordinarily under 0.3 mg/liter yet might be higher in countries where different iron salts are utilized as coagulation chemical in water treatment processes.

2.9.2.1 Health Effects of Iron

Iron is a basic component in human nourishment. It can catalyze biochemical reactions including the arrangement of radicals which can harm biomolecules, cells, tissues and the entire living being. Iron damage has consistently been a subject of intrigue to pediatricians. Children are very helpless to substances containing iron in high amounts (Albertsen, 2006; Jaishankar *et al*., 2014). Acute exposure to iron may lead to hypotension, tachycardia, hepatic rot, lethargy, metabolic acidosis and diarrhoea.

2.9.3 Manganese (Mn) in Water

Rock and soil are the main hubs for naturally occurring manganese. They are also found essentially in food and other nourishment, including manganese-containing supplements. Additionally, people who take a lot of tea may have higher levels of manganese than the normal individual. Certain occupations like welding or working in a manufacturing plant where steel is made, may be a source of exposure to large amounts of manganese (ATSDR, 2012). Manganese is utilized primarily in steel production to improve hardness, strength and stiffness. It is utilized in carbon steel, treated steel, high-temperature steel, and device steel, alongside cast iron and super composites (ATSDR, 2012).

2.9.3.1 Health Effects of Manganese

"Manganism" is a disorder brought about by abnormal exposure to manganese from fumes and dust. It presents a Parkinson-like syndrome with symptoms such as weakness, anorexia and muscle pain, apathy and slow speech, monotonous tone of voice, emotionless "mask-like" facial expression and slow, clumsy movement of the limbs. For the most part, these deformities are irreversible (ATSDR, 2012).

2.9.4 Fluoride (F) in Water

Fluorine is a typical component that is broadly conveyed in Earth's outer layer and exists as fluorides in various minerals, such as, fluorspar, cryolite and fluorapatite (World Health Organization, 2006). In certain regions where fluoride-containing minerals are common, well water may contain up to 10 mg of fluoride for every liter, albeit a lot higher levels can be found. Tea specifically can contain high fluoride contents, and levels in dry tea may reach 100 mg/kg due to the fact that many vegetation types contain fluoride obtained from the soil and water (Lennon *et al*., n.d.). Fluorine compounds are utilized in many industrial processes for producing a wide variety of items. They can likewise be discharged into the environment in the manufacture of phosphate composts, blocks, tiles and earthenware products. Fluorosilicic acid, sodium hexafluorosilicate and sodium fluoride are utilized in water fluoridation systems (IARC, 1982; IPCS, 2002; World Health Organization, 2006).

2.9.4.1 Health Effects of Fluoride

Fluoride consumption from drinking water is taken up and conveyed all through the blood (Aggeborn and Öhman, 2017; Fawell *et al*., 2006, p.29-30). A lot of studies on fluorides have focused on skeletal fluorosis, fractured bones, tumors birth defects and other conditions which are said to be triggered by fluoridation (Lennon *et al*., n.d.; World Health Organization, 2006). There is however no proof of any harmful therapeutic impacts related with the utilization of water with fluoride levels of 0.5 – 1.0 mg/liter other than the expansion in dental fluorosis. After all said in done, dental fluorosis does not happen in temperate territories at levels between 1.5 - 2 mg of fluoride for every liter of drinking water. It is conceivable that in territories where fluoride in take through pathways other than drinking water are considered, dental fluorosis will develop at levels lower than 1.5 mg/liter of drinking water (Cao *et al*., 1992; World Health Organization, 2006).

2.9.5 Nitrate (NO_3^-) in Water

Several agricultural practices particularly fertilizer applications introduce nitrate in the soil which may subsequently contaminate surface water during run-offs from rains and ground water as well. Another key source of contamination by nitrate are animal and human faeces as a result of open defecation and sewage or septic tank leakages in municipal waste treatment. Nitrate polluted drinking water can have debilitating effect on humans mostly infants. Through the activities of bacteria, nitrate can further be broken down to the less stable form nitrite which is even more hazardous in the environment (World Health Organization, 2011).

2.9.5.1 Health Effects of Nitrate

The danger of nitrate to people is for the most part inferable from its decrease to nitrite. The major organic impact of nitrite in people is the inclusion in the oxidation of ordinary hemoglobin (Hb) to methaemoglobin (metHb), a circumstance which interferes with the movement of oxygen to the tissues. The diminished oxygen transport brings about the condition, called methaemoglobinaemia, (causing cyanosis and, at higher levels, asphyxia), when metHb levels achieve 10% of typical Hb levels or more. The ordinary metHb level in people is under 2% and in newborn children under 3 months of age, it is under 3% (World Health Organization, 2011). Various other epidemiologic examinations have mentioned a relationship between reproductive health issues, including a few birth defects because of introduction of pregnant ladies to raised levels of nitrate in drinking water, (Iowa Environmental Council, 2016; Brender & Weyer, 2016; Manassaram *et al.*, 2006). Further, investigations have demonstrated a connection between high contents of nitrate in drinking water and urinary bladder malignancy (American Cancer Society, 2016; Jones *et al*., 2016).

2.10 Physical Parameters

2.10.1 Turbidity

Turbidity can indicate the presence of pathogenic microorganisms and may be an effective indicator of hazardous events throughout any water supply system. For example, high turbidity in sources of water can inhabit microbial pathogens, which can be attached to particles and impair disinfection. Again high turbidity in filtered water may point to poor removal of pathogens and an increase in turbidity in distribution systems can indicate scale of oxides and formation of biofilms (World Health Organization, 2017). Turbidity may also be caused by various component particles including silt, clay and chemical constituents like iron and manganese as well as organic matter (APHA/AWWA/WEF, 2012; Health Canada, 2012), all of which may convey the presence of bacteria in the drinking water. Therefore, high turbidity measurement is a course for concern in any water analysis procedure. It is therefore vital to incorporate it in all water assessment programmes because of the ramifications for water quality (World Health Organization, 2017).

2.10.2 pH

The negative logarithm of the hydrogen ion is the pH of a solution. The pH of normal water is 6.5-8.5. It is a significant parameter for controlling the destructive characteristics of water in distribution pipes. For thorough purification with chlorine, pH ought to ideally be under 8, in order to be well managed. Inability to control pH can bring about water deterioration which can influence the taste, scent, and appearance. Temperature influences pH estimation fundamentally, thus it is recorded as a component of water investigation. Because of the impact of pH on the adequacy of sanitization and corrosion of pipes, it is incorporated at all degrees of appraisal as a key parameter (WHO, 2011).

2.10.3 Conductivity and Total Dissolved Solids

The capacity of water to conduct electricity is conductivity. It can be viewed as an intermediary pointer of total dissolved solids (TDS) and, in this way, of its taste and salinity which basically contain mineral salts. While there is minimal direct adverse health effects related to this property, elevated levels are related to inferior taste, and thus consumer disappointment (WHO and UNICEF, 2012). There is no WHO health grounded limit for conductivity yet it is commonly accepted that drinking water tend to be progressively unpleasant at concentrations over 1400 µS/cm (being identical to TDS estimation of around 1000 mg/l) (WHO, 2011a). In spite of the fact that this parameter does not give data about specific pollutants, it can be used as a marker for judging the quality of water. It is prescribed as a parameter in all degrees of water appraisal.

CHAPTER THREE

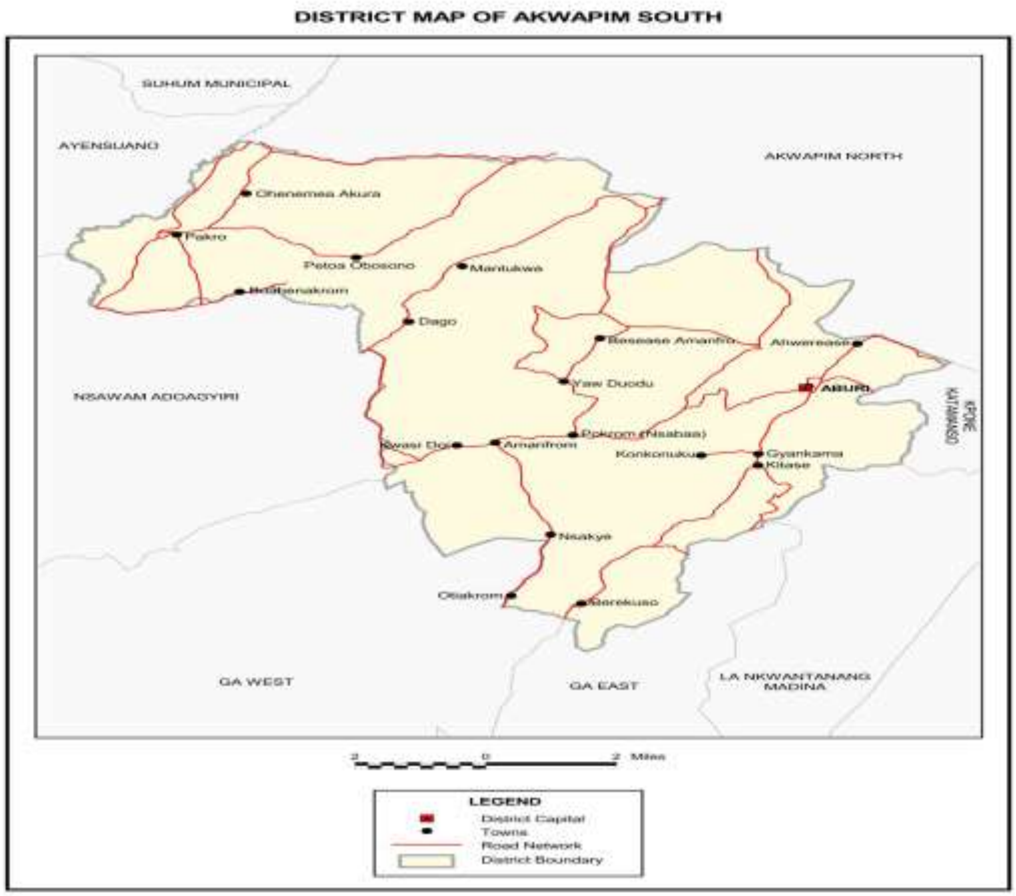
3.0 MATERIALS AND METHODS

3.1 Study Area

The Akuapem South District is one of the recently created districts in the Eastern Region of Ghana, established on the 6th of February 2012 by an Act of Parliament (Legislative Instrument 2040). The district was carved out from the old Akuapem South Municipality and has Aburi as the capital, which is about 20km from Accra, the national capital with a population of 37,501 (Ghana Statistical Service, 2014). The Akuapem South District is located at the south eastern part of the Eastern Region of Ghana, between latitudes 5.45º N and 5.58º N, and longitude 0º, covering a land area of about 224.13 square kilometres. It is bordered on the west by the Nsawam-Adoagyiri Municipality, on the south-east by the Kpone-Katamanso District, on the south by the Ga East District and on the North-East by the Akuapem North Municipality (Ghana Statistical Service, 2014).

The inhabitants are predominantly Akuapems, who are part of the Akan ethnic group, with the main dialect being Akuapem Twi. More than one third of the labour force are employed in the agriculture sector with majority being engaged in crop farming. The district is one of the leading producers of pineapples, mangoes and citrus fruits in the country (Ghana Statistical Service, 2014). It is blessed with some of the historical sites in the country. These include the Peduase Lodge which is a Presidential Lodge built by the first President of Ghana, Dr. Kwame Nkrumah. Another attractive tourist site in the study area is the Aburi Botanical Gardens which was established by the Basel Missionaries in 1890 and situated in Aburi, the district capital. The Aburi Botanical Gardens does not only serve as a tourist centre for people but also harbours rare species for biodiversity. The species are important for both aesthetic and scientific purposes. Some of the trees serve as medical plants. On the average, Aburi Botanical Gardens receive about 35,000 visitors per annum raking in a lot of revenue for the district (Ghana Statistical Service, 2014). Majority of the inhabitants do not have a regular supply of good drinking water and therefore resort to the use of water from unprotected sources. Also, sanitation is generally poor as majority of the people in the district do not have adequate toilet facilities and so practice open defecation and improper refuse disposal which exposes the water sources to possible contamination by hazardous substances from waste matter. In addition, majority of the inhabitants who are farmers use agrochemicals, which could be washed into the water sources resulting in further pollution. Quarrying activities that take place at the foot of the ridge to supply aggregates for the construction industry could also be another source of pollution as run-offs from rain could wash particles of rock into these water sources.

3.1.1 Map of Study Area



Source: Ghana Statistical Service, GIS

Figure 2: Map of Akuapem South District

3.2 Study Design

This water assessment is a cross sectional study which was carried out in five (5) rural towns in the Akuapem South District. A multi-stage sampling technique was used to enroll participants for the study. The towns were grouped into rural and urban areas with the focus on rural towns due to their vulnerability in terms of water availability and accessibility. A household list from the 2010 population and housing census was then used as sample frame to select the towns based on their strategic location, total number of households in the community and the prevailing socio-economic activities. From the complete list of households, respondents were selected by systematic random technique for questionnaire administration to elicit demographic information, water supply sources, behaviours relating to household water treatment methods, sanitation and hygiene practices, including hand washing practices.

A total of 215 questionnaires were administered in addition to 30 household water samples collected for quality analysis. The administration of questionnaire began from a home with storage vessel or container. Subsequently, every 4th house and 4th household was selected to be interviewed. Simultaneously, samples of water were collected from every 7th household that stored water until the total sample size was collected. In the event that there was no one in a house, the next house on the list was interviewed.

3.3 Study Variables

3.3.1 Dependent (Outcome) Variables

- *Escherichia coli* and Thermotolerant Coliforms (TTC)

3.3.2 Independent Variables

- Water source
- Water storage
- Fetching vessel
- Storage vessel
- Vessel cover
- Hand washing practices
- Water treatment
- Toilet in house
- Distance to toilet
- Animal in house

3.4 Sample Size Calculation

The Yamane (1967) formula which assumes that a random sampling gives an equal chance of being selected with an error margin of 0.05 and 95% confidence interval was utilized to calculate a minimum sample size. Based on a similar studies conducted by

Duodu (2014), Trevett *et al*., (2004), Vankatesen *et al*., (2014), Asiedu (2014) and Boateng & Adam (2013), whose sample size ranged from 31, 43, 51, 106 and 250 respectively, a minimum sample size of 195 was calculated using the formula below:

$$n = \frac{N}{1 + Ne^2}$$

Where, n= sample size

N= sample population

e = level of precision

A final sample size of 215 was obtained by adding 10% of the minimum sample size (195) calculated from the formula. The 10% (20 individuals) added was to cover for non-response (Ronoh and Kyalo, 2009).

3.5 Pre-Sampling Preparation

Research assistant (RAs) were recruited and given adequate training. The content of the training involved; the purpose and objectives of the study, data collection techniques as well as tools to be used, questionnaire translation into the local (Twi) language, data collection ethical guidelines. The principal investigator was part of the research team during the interviews to ensure that relevant information in line with the study objectives were collected and adherence to ethical standards was maintained. The questionnaires were verified for inaccuracies and comprehensiveness before community entry. To minimize errors, pre-testing of the data collection tools was done on 10% of the sample size in a nearby community. Revision of the questionnaires was done based on the results of the pilot study. The findings of the pre-test was used to improve the validity of the data collection tools and the reliability of the research findings. Meanwhile, sampling containers with well-fitted stoppers were rinsed with acetone to remove traces of organic substance like fat residues and greases, after which the bottles were washed with liquid detergent, rinsed with de-ionized water and soaked in 1.0 M nitric acid solution for 24 hours. The containers were rinsed several times with de-ionized water before sample collection. Sample containers for microbiological analysis were sterilized in an autoclave at 121 ºC, for 15 minutes to remove any form of contamination (Who & Unicef, 2012). The washing and sterilization of containers were necessary to prevent any allochthonous contaminants from interfering with the results.

3.6 Data Collection Procedure

After obtaining informed consent, face-to-face interview using a structured questionnaire was employed to gather data from individuals in a household. Demographic information and behavioural patterns of respondents including water transport, storage and handling, general hygiene practices as well as their sources of drinking water were collected to determine possible sources of contamination in the households. Simultaneously, samples of stored household water were collected from storage containers in the homes of households for quality analysis. At the household, respondents were made to provide a glass of water that they use for drinking. The water samples were then collected into the pre-washed and pre-labeled 1 L sample bottles obtained from the laboratory. The bottles were rinsed with sample water prior to sample collection for the physico-chemical parameters, whereas, the sterilized bottles were used to collect microbiological samples directly without rinsing.

3.7 Sample Analysis

Bacteriological, physical and chemical analysis were conducted on samples by employing methods outlined in the Standard Procedures for Examination of Water and Wastewater by the American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF) (APHA, 2005). Sample analysis was carried out in duplicates and the data presented as means. *E. coli* and thermotolerant coliforms (TTC) were the bacteriological parameters analyzed and turbidity, pH, conductivity, total dissolved solids and temperature were tested in-situ for physical parameters, while chemical parameters included nitrate, arsenic, fluoride, iron and manganese. Samples for bacteriological analysis were transported on ice pack in an ice chest to the laboratory within 6 hours after sampling and stored in a refrigerator at 4 ºC. Samples collected for chemical analysis were preserved by the addition of concentrated nitric acid (1.5 mL/L) to prevent deterioration during storage.

3.7.1 Bacteriological Analysis

The most accurate method accepted internationally as a standard method for testing the quality of water by determining the number of indicator bacteria in a water sample is the membrane filtration (MF) technique. This technique gives an immediate tally of thermotolerant and total coliforms that may be present in a given water sample. A measured volume of water is filtered through a membrane filter comprising a cellulose compound with a uniform pore size of 0.45 μm or 0.2 μm in diameter. After the filtration procedure, bacteria are retained on the surface of the membrane filter. The membrane filter is placed in a petri dish containing a selective differential culture medium and incubated at a suitable temperature. Characteristic colonies indicating thermotolerant coliforms develop and are directly tallied.

Procedure

An Erlenmeyer flask with side-arm was connected to a vacuum source and the porous support placed in position. The filtration unit was assembled by placing a sterile membrane filter on the porous support, using forceps sterilized by flaming and the upper container positioned to secure it. 10 mL of water sample was poured into the upper container and filtered by applying the vacuum. After filtration the membrane filter was placed in the Petri dish containing Chromogenic coliform agar with the grid side up using the sterile forceps and making sure that no air bubbles were trapped between the pad and the filter. The Petri dish was left at room temperature or at 35 or 37 °C for 2–4 hours, for resuscitation of stressed microbes. It was then transferred into an incubator at 44 ± 0.5 °C for 24 hours with 100% humidity for thermotolerant coliforms and 37 ºC for *Escherichia coli* (WHO & UNICEF, 2012).

The colonies of thermotolerant coliform bacteria were identified from their characteristics on the medium used. The number of thermotolerant coliforms per 100 ml was given by:

$$\text{Thermotolerant coliforms per 100 mL} = \frac{\text{No. of thermotolerant coliform counted x 100}}{\text{Vol in (mL) of sample filtered}}$$

3.7.2 Physico-chemical Analysis

Standard methods found in the Examination of Water and Wastewater (APHA, 2005) were used for the analysis of samples. Turbidity, pH, TDS, Conductivity and Temperature were the physical properties tested in-situ (on-site), with the use of a multi-probe meter, model (Horiber U50 series) by HACH. The meter was switched on and the probe placed in a beaker containing the water sample. The read button was pressed and the results for the physical parameters displayed was recorded. The SPADNS method was used to analyse Fluoride content (APHA, 2005). Nitrate was tested using HACH direct reading spectrophotometer method, while manganese, iron and arsenic were analysed with Atomic Absorption Spectrophotometer (AAS) model: Varian 240FS.

3.7.2.1 Sample pretreatment

For the trace metals (As, Mn, Fe), the water sample which had been preserved with acid was thoroughly mixed and a 100 mL volume transferred into a flask. A 5 mL volume of concentrated nitric acid (HNO_3) was then added in a fume hood. To prevent spattering, boiling chips (glass beads) were added to the mixture. The mixture was boiled slowly and allowed to evaporate on a hot plate at low temperature until digestion is complete which is indicated by a clear, light-coloured solution. When digestion was complete, distilled water was used to rinse the walls of the flask after which the solution was filtered. A 100 mL volumetric flask was used to collect the filtrate after two 5 mL portions of distilled water had been used to rinse the digestion flask. The filtrate was allowed to cool, diluted to the mark and thoroughly mixed. The atomic absorption spectrometer (AAS) was then used to analyse the water sample for the following metal contaminants (As, Mn, Fe).

3.7.2.2 Total Iron

The acidified water sample was aspirated directly into the AAS with an air-acetylene flame and atomized for the determination of total iron. The concentration of iron was determined using a hollow cathode lamp specific for iron detection. The AAS measures the absorbance of iron at a wavelength of 264 nm, equivalent to the concentration of iron in the water sample. A blank and standard solutions were used to calibrate the AAS before commencing analysis of the elements. To eliminate or minimize interference from other elements, ionization buffers and matrix modifiers were added to the sample (APHA, 2005).

3.7.2.3 Manganese

The concentration of manganese was determined by the direct aspiration of acidified sample into an air-acetylene flame and atomized in an atomic absorption spectrophotometer (model: Varian 240FS). A hollow cathode lamp specific for manganese detection was used to measure the concentration of manganese ions in the water sample. The AAS measures the absorbance of manganese at a wavelength of 279.5 nm, equivalent to the concentration of manganese in the water sample. A blank and standard solutions were used to calibrate the AAS before commencing analysis of the elements. To eliminate or minimize interference from other elements, ionization buffers and matrix modifiers were added to the sample (APHA, 2005).

3.7.2.4 Arsenic

The electrothermal atomic absorption spectrometric method was used for the determination of total recoverable arsenic. A 100 mL of the thoroughly mixed water sample was treated with 1 mL conc HNO_3, and 2 mL 30% H_2O_2 into a clean, acid-washed 250 mL beaker. The sample was heated on a hot plate without boiling until the volume reduced to about 50 mL, and then allowed to cool to room temperature off the hot plate. An appropriate concentration of nickel was added and diluted to volume in a 100 mL volumetric flask with water. A measured portion of the sample was injected into the graphite furnace with an automatic sampler or a micropipette and the absorbance read at the appropriate wavelength after the instrument had been calibrated with the blank solution.

3.7.2.5 Nitrate (NO_3^-)

HACH spectrophotometer model DR 2010 was used in the measurement of nitrate in the water sample. A 10 mL sample was pipetted into a cuvette and one sachet of nitrate powdered pillow (Nitra Ver 5) added. The sample was swirled severally for a minute and allowed to stand for a further 5 minutes to ensure complete reaction until the appearance of an orange colour, indicating the presence of nitrate. A solution blank was used to zero the equipment after which the concentration (mg/L) of nitrate in the sample was measured at a wavelength of 543 nm. This method was the Cadmium reduction method.

3.7.2.6 Fluoride

The SPADNS method was exploited in the measurement of fluoride concentration in the water samples. 25 mL of the water sample was transferred into a sample cuvette and 5 mL of SPADNS reagent added. The solution was thoroughly mixed by swirling and allowed to stand for 1 minute for the reaction to be completed. A solution blank was simultaneously prepared following the steps above after which it was used to zero the spectrophotometer. The fluoride content in the water samples were then measured at 580 nm wavelength and the reading recorded.

3.8 Quality Control

For the water quality analysis, a blank and standard were analyzed between samples to verify baseline stability and the instrument zeroed when necessary. To one sample out of every ten a known amount of the metal of interest was added and analyzed to confirm recovery. The amount of metal added was approximately equal to the amount found when measured. In addition, standard solutions were analyzed after every ten samples or with each batch of samples, as part of the quality control measures.

With regards to the social survey, validity of results was ensured by discussing the errors and omissions detected in the administered questionnaires with the respective research assistants for completeness and appropriate corrections were made before final entry into Microsoft spreadsheet (Excel) for statistical analysis.

3.9 Data Analysis

STATA version 15 was used for the statistical analysis after Microsoft spreadsheet (Excel) 2013, had been utilized to clean and code raw data collected from the field. The means, standard deviations, minimum and maximum values, indicating water quality were generated from the microbial and physico-chemical parameters, whereas, descriptive statistics such as proportions, frequency and cross-tabulations were used to depict the demographic attributes of the study population. Multivariate logistic regression was used to determine the association between the dependent and independent variables in relation to behavioural patterns including water handling and storage, hygiene and sanitation practices. In addition, a one-way analysis of variance (ANOVA) was used to test for differences in the mean water quality among selected towns.

3.10 Inclusion and Exclusion Criteria

The inclusion criteria were households that formed part of the random sample within the five (5) selected rural towns in the Akuapem South District and were available at the time of sampling whereas, the exclusion criteria were households with individuals who for some reason would not be available during the questionnaire administration.

3.11 Ethics Considerations

The Ethics Review Board of the Ghana Health Service approved this study before data collection was embarked upon. A copy of the letter is attached to this document (Appendix III). Permission was also sought from the Akuapem South District and participants' consent were obtained before being enrolled onto the study.

3.11.1 Access and Approval of Study Area

The principal investigator visited the study area personally to notify the management of the district with a letter about the intent to conduct this study. A copy of an introductory letter signed by the Head of Department of the Biological, Environmental and Occupational Health Sciences of the School of Public Health, University of Ghana, attached to the permission letter was given to the District Chief Executive (DCE) of the district for permission to conduct this study. Subsequently, a copy of the approval letter from the Ethics Review Board of the Ghana health Service was also presented to the DCE.

3.11.2 Privacy and Confidentiality

To ensure privacy and confidentiality, the questionnaires were coded without names of respondents. The interview was conducted in an area where participants were comfortable and their privacy was guaranteed. Participants' names were not mentioned in the final report of the study and information gathered on participants were strictly kept in confidence.

3.11.3 Compensation

Study participants were not given any compensation for taking part in this study. This was made known to them before they were enrolled into the study.

3.11.4 Risks and Benefits

The study did not entail any invasive risks, however, one might have felt uncomfortable with some of the questions that were asked, resulting in some minimal loss of privacy and confidentiality as well as time spent in completing the questionnaire. The findings were shared with authorities of the district and other stake-holder institutions who have interest in improving the quality, safety, accessibility and availability of drinking water in the community including future policy formulations, all of which may lead to improvement of the health and well-being of members of the community.

3.11.5 Voluntary Withdrawal

Taking part in this study was entirely optional and respondents had a choice to decline questions they were uncomfortable with. Participants were within their rights to pull out of the study at any point in time without prior notice. However, they were encouraged to fully participate to ensure that findings from the study reflected the factors being investigated.

3.11.6 Informed Consent and Consenting Process

Informed consent were obtained from participants before commencement of the study. Respondents in the study were contacted in person and the objectives thoroughly explained to them before seeking their informed consent. They were then made to sign a written consent form after a detailed explanation had been given to them and they elect to be part of the study. The decision to participate in the study was entirely voluntary.

3.11.7 Data Storage and Usage

Data collected in this study were strictly for research purposes. The data were stored with passwords on electronic media and safely locked boxes. Anonymity was ensured in dissemination of findings from this study as participants were not identified by names.

3.11.8 Declaration of Conflict of Interest

Apart from the fact that this study was conducted in partial fulfilment of the requirement for the award of a Master's degree, there is no conflict of interest on the part of the principal investigator.

CHAPTER FOUR

4.0 RESULTS

4.1 Response Rate from Questionnaire Administration

A total of 215 complete responses were obtained from the questionnaires administered to the systematically selected households in all five (5) surveyed towns in the study area with a response rate of 100%.

4.1.1 Demographic characteristics of households

Table 1, below shows the demographic characteristics of households captured as part of this survey. More than two-thirds 164 (76.3%) of respondents were females compared to only 51 (23.7%) who were males. Majority 84 (39.1%) of the respondents in the study area were within the age category of 40-49 years, with 63 (29.3%) being in the 30-39 years category, followed by 38 (17.7%) in the 18-29 years age brackets while only 30 (13.9%) were above the age of 50 years. With regards to the level of education, less than half (44.2%) of households in the study area had basic education, whereas only 12.1% had secondary education. Thirteen per cent (13%) were educated to the tertiary level, with 30.7% uneducated. The main occupation of households in the study area was found to be farming, constituting 32.6%, followed by trading 26.9%, while, 12.1% were employed by government. Twenty per cent (20.0%) of households were self-employed with just a few (8.4%) reported being unemployed. More than three-quarters 169 (78.6%) of households were made up of at least four (4) people, whereas 46 (21.4%) were made up of three (3) people or less.

Table 1: Demographic characteristics of household representatives in study area

Variable	Frequency (N = 215)	Percent (%)
Sex of respondent		
Male	51	23.7
Female	164	76.3
Age of respondent		
18-29	38	17.7
30-39	63	29.3
40-49	84	39.1
≥ 50	30	13.9
Education level		
Basic	95	44.2
Secondary	26	12.1
Tertiary	28	13.0
None	66	30.7
Occupation of respondent		
Farming	70	32.6
Trading	58	26.9
Gov't Employed	26	12.1
Self Employed	43	20.0
Unemployed	18	8.4
Number of Persons in Household		
≤ 3	46	21.4
≥ 4	169	78.6

4.1.2 Water Sources

When asked for a glass of water that the respondents used for drinking, they provided samples from household storage containers. Four (4) main sources of drinking water were identified from responses in selected households in all five (5) surveyed towns, as summarized in Table 2 below. These were borehole, well, pipe and streams. Majority of households (81.4%) depended on borehole stored water only as their main source of drinking water. A further 14% used well water, while very few households (3.7%) depended on pipe water as their sole source of drinking water. Only 0.9% used water drawn from other sources like streams, rivers and springs. About a quarter (24.2%) of households reported using a secondary source of water in addition to their primary source, while a little over three-quarters (75.8%) reported using only their primary source of water. Only 33% of households in the selected towns had access to an improved source of water within a 30-minute walk, in contrast to 67% who had to make more than 30 minutes round trip to access water for their daily use, with more than two-thirds (72.5%) of households having to collect water in a wide-mouthed pan over long distances to be stored in the house, compared with only 0.5% of respondents who collected and transported water in a jerry can. Although, all the households interviewed (100%), reported that water was stored in a storage vessel, 80.9% reported storing the water in drums, compared with only 6.5% who used tanks as their storage vessel. Of these storage vessels, at least 87% were made of plastic, compared to only 13% which were made of steel, Table 2. The survey showed that only a small number (14), constituting 6.5% treated their water by boiling before drinking.

Table 2: Water sources and handling practices among households

	N = 215	
Variable	**Frequency**	**Percent (%)**
Water Source		
Borehole	175	81.4
Well	30	14.0
Pipe	8	3.7
Others	2	0.9
Additional Water Sources		
Yes	52	24.2
No	163	75.8
Time for Collection		
≤ 30 minutes	71	33.0
> 30 minutes	144	67.0
Water Collection Vessel		
Bucket	26	12.1
Jerry Can	1	0.5
Wide-mouthed Pan	156	72.5
≥ 2	32	14.9
Water Storing Vessel		
Drum	174	80.9
Barrel	27	12.6
Tank	14	6.5
Vessel Type		
Plastic	187	87.0
Metal	28	13.0
Multiple Vessel Storage		
No	215	100
Water Treatment		
Yes	14	6.5
No	201	93.5
Treatment Method		
Boiling	14	6.5
No response	201	93.5

4.1.3 Water Hygiene Practices

Table 3 below, summarizes data on water hygiene practices among the households. As shown, a small number (7) constituting just 3.2% practiced hand washing regularly, whereas, less than half (40.5%) did not practice hand washing at all, and more than half (56.3%) reported that they wash their hands sometimes. All households in the study area reported cleaning their storage vessels at intervals, however, only 31.6% reported cleaning their vessels every week, whereas, less than half (43.7%) clean the vessels monthly and less than a quarter (24.7%) reported cleaning the vessels every quarter. Out of the 215 households interviewed, almost all, representing 98.6% withdrew water from the storage vessels with cup, while only 1.4% did so by pouring. Again, majority of respondents (86.1%) reported covering their vessels with a lid with just 13.9% who did not have a lid to cover their vessels. With the exception of 0.9% of households who reported having a separate vessel for storing drinking water, the greater majority (99.1%) used their stored water for purposes other than drinking.

Table 3: Water hygiene practices among households

Variable	N = 215 Frequency	Percent (%)
Hand Wash Practice		
Yes	7	3.20
No	87	40.5
Sometimes	121	56.3
Vessel Cleaning Frequency		
Weekly	68	31.6
Monthly	94	43.7
Quarterly	53	24.7
Water Withdrawal		
Pouring	3	1.40
Cup	212	98.6
Cover on Vessel		
Yes	185	86.1
No	30	13.9
Multiple Water Use		
Yes	213	99.1
No	2	0.90

4.1.4 Sanitary Practices of Households

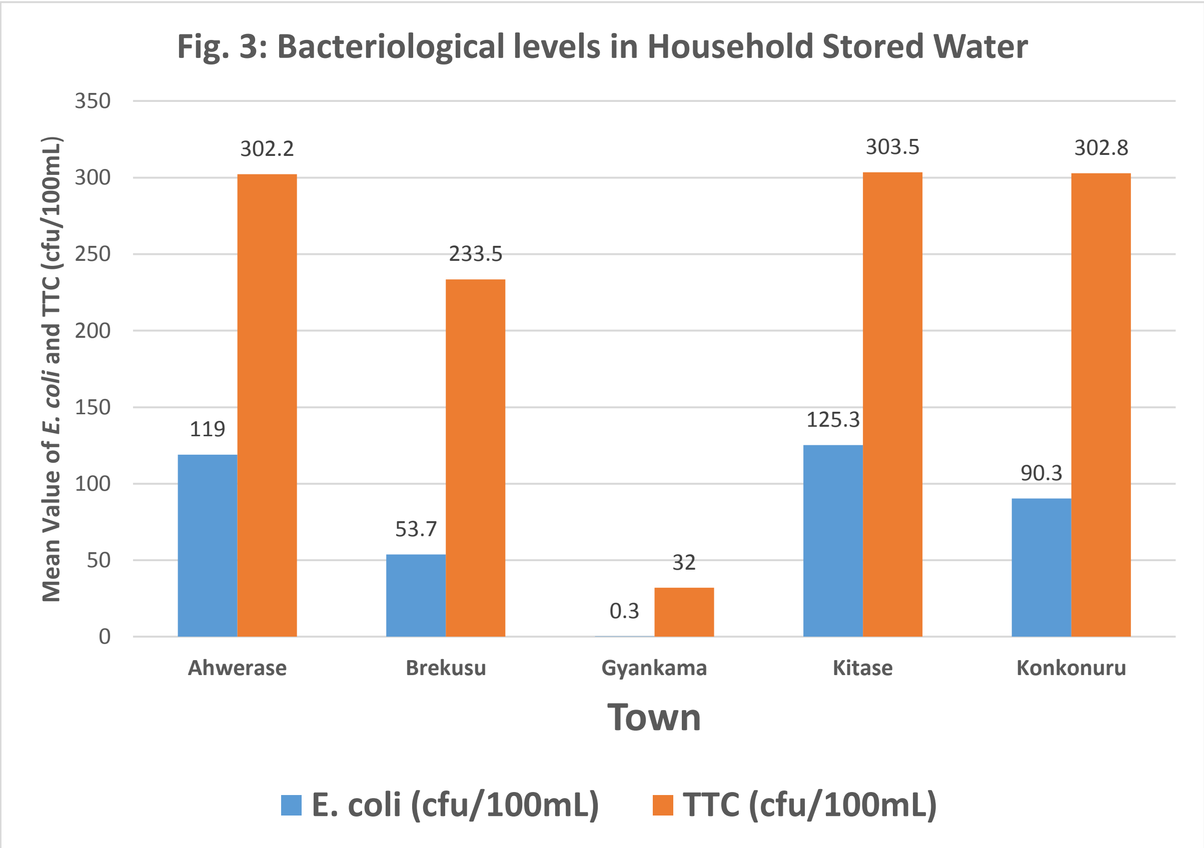
The proportion of households with toilet facilities (40.5%) and within a 10 metre radius (38.1%) were fewer than those without toilet facilities (59.5%) and had to walk more than 10 metres radius (61.9%) to access a toilet facility, Table 4 below. Close to two-thirds (62.3%) of households reported keeping animals in their homes while at the same time, a greater majority (95.8%) kept clean surroundings in and around the place where they keep their stored water. The survey revealed that all the households (100%) kept their storage vessels on the ground level and that no part of their vessels leaked.

Table 4: Sanitary practices among households

	N = 215	
Variable	**Frequency**	**Percent (%)**
Toilet in House		
Yes	87	40.5
No	128	59.5
Distance to Toilet		
≤ 10 metres	82	38.1
> 10 metres	133	61.9
Animals in House		
Yes	134	62.3
No	81	37.7
Vessel Leak		
No	215	100
Vessel Kept on the Ground		
Yes	215	100
Clean Surroundings		
Yes	206	95.8
No	9	4.20

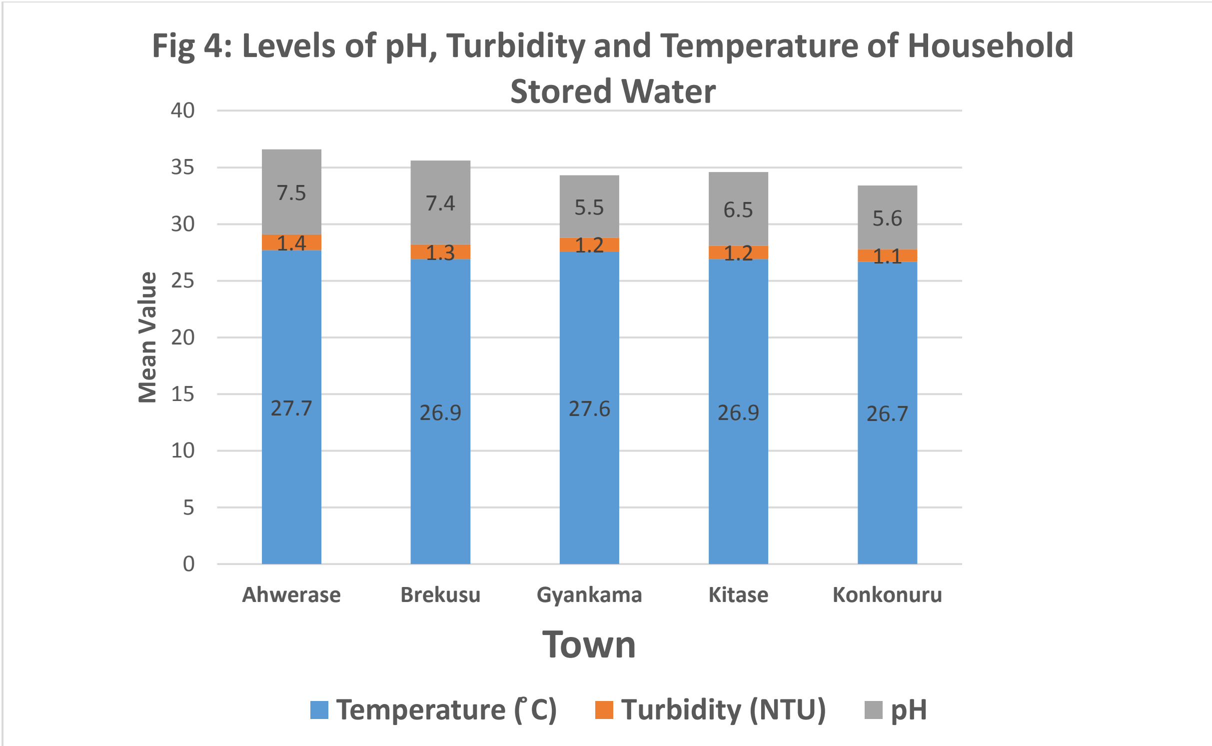
4.2 Bacteriological quality of household stored water

Fig. 3 below shows the disaggregated results of *Escherichia coli* (*E. coli*) and thermotolerant coliform (TTC) among the surveyed towns. The mean *E. coli* and TTC levels ranges from 0.3–125.3 cfu/100mL and 32–303.5 cfu/100mL respectively, among the towns. *E. coli* levels were generally low as it was detected in 80% of all household water samples analysed, compared with the levels of TTC which was present in all (100%) household water samples analysed in the study area. Households in Gyankama recorded the lowest levels of both *E. coli* and TTC counts in contrast with the other towns, while Kitase recorded the highest bacteriological levels.

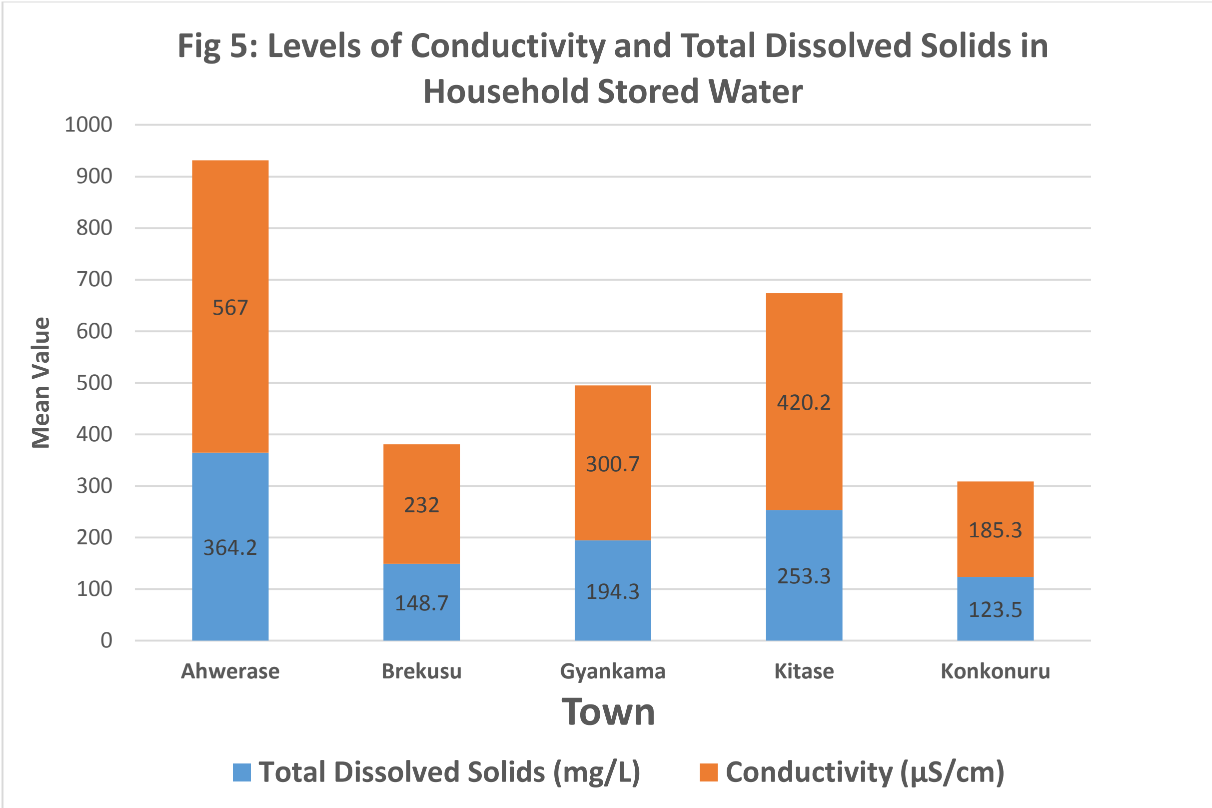


4.3 Physico-chemical quality

For any drinking water to be acceptable to consumers, the pH must fall within a range of 6.5-8.5 and turbidity must not exceed 5 NTU (nephelometric turbidity unit) as recommended by the WHO guidelines on drinking water quality (GDWQ). The disaggregated results in Fig. 4 below shows the levels of pH, turbidity and temperature of stored household water in the selected towns. The pH ranged from a minimum of 5.5 to a maximum of 7.5. Gyankama recorded the lowest pH of 5.5, while Ahwerase recorded the highest of 7.5. Meanwhile, the pH for Gyankama (5.5) and Konkonuru (5.6) were below the acceptable limits for drinking water. On the other hand, the turbidity of household stored water samples measured in the study area were all within the required limits. The turbidity ranged from a minimum of 1.1 NTU to a maximum of 1.4 NTU. The temperature of household stored water among selected towns ranged from a minimum of 26.7 ºC to a maximum of 27.7 ºC, Fig. 4. Konkonuru recorded the lowest, while Ahwerase recorded the highest water temperature in the study area. A one-way analysis of variance (ANOVA) at 95% confidence interval, showed that there is significant difference in the mean pH levels among the selected towns ($p < 0.001$) whereas, turbidity and temperature were not statistically significant ($p = 0.59$ and 0.17 respectively).



The disaggregated results on conductivity and total dissolved solids (TDS) are shown in Fig. 5 below. The concentrations of conductivity and total dissolved solids (TDS) ranged from a minimum of 185.3 µS/cm to maximum of 567 µS/cm and 123.5 mg/L to 364.2 mg/L respectively among households in selected towns. Ahwerase recorded the highest mean values for both conductivity and TDS compared with the four other towns, whereas, Konkonuru recorded the lowest mean concentrations measured in the study area (Fig. 5). The levels of conductivity and TDS measured for all the towns were within the acceptable limits per the WHO guideline on drinking water quality. A one-way ANOVA at 95% confidence interval showed a significant difference ($p < 0.001$) in the levels of conductivity and TDS measured among all selected towns in study area.



Of the five (5) chemical parameters analysed, only nitrate was detected with the other four (fluoride, arsenic, iron and manganese) not detected in the household stored drinking water samples. The concentrations of nitrate as determined were all within the acceptable limits as indicated in Table 5 below. A one-way ANOVA at 95% confidence interval showed a significant difference ($p < 0.001$) in the levels of nitrate recorded among all the selected towns in study area.

4.4 Summary of Water Quality Analysis

Stored drinking water samples were collected at the households (point of use) for bacteriology and physico-chemical analysis in the laboratory after questionnaire administration, and Table 5 below shows a summary of the aggregated results.

Table 5: Summary of Laboratory Results on Quality of Household stored water

Parameter	Mean	±SD	Minimum	Maximum	WHO Guideline
Bacteriology					
E. coli (cfu/100 mL)	77.7	99.15	0	300	0
TTC (cfu/100 mL)	232.8	115.8	2	300	0
Physical					
pH	6.5	0.89	5.2	7.9	6.5-8.5
Turbidity (NTU)	1.24	0.31	0.92	2.26	≤ 5
Total Dissolved Solids (mg/L)	216.8	115.6	109	537	≤ 1000
EC (µS/cm)	341	183.9	168	839	≤ 1400
Temperature (℃)	27.2	0.85	25.9	30.6	-
Chemical					
Nitrate (mg/L)	1.59	1.01	0.5	4.5	≤ 50
Fluoride (mg/L)	ND	ND	ND	ND	≤ 1.5
Arsenic (mg/L)	ND	ND	ND	ND	≤ 0.01
Iron (mg/L)	ND	ND	ND	ND	≤ 0.3
Manganese (mg/L)	ND	ND	ND	ND	≤ 0.4

SD - Standard Deviation, ND - Not Detected, TTC - Thermotolerant Coliform, *E. coli* - *Escherichia coli*, EC - Electrical Conductivity, WHO - World Health Organization

4.5 Association between Water, Sanitation and Hygiene and *E. coli* load

In order to predict the faecal contamination of household drinking water using the water, sanitation and hygiene practices of the people in the study area, *E. coli* count was used as the dependent variable, while hand wash, distance to toilet, presence of animals in the homes, time spent to collect water and water source were used as the independent variables, in a multivariate regression analysis, Table 6 below. Both crude and adjusted odds ratios indicate that households who washed their hands sometimes were at a lower risk of contaminating their stored water (OR=0.47; 95% CI 0.04, 5.26) and (AOR=0.65; 95% CI 0.05, 8.25) respectively, compared to those who did not wash their hands at all. The regression results however, revealed that although the independent variables, influenced the faecal contamination of stored household drinking water, it was not statistically significant. Notwithstanding, the crude odds ratio and adjusted odds ratio both revealed the similar trend in either reducing or increasing the *E. coli* count in household water samples with regards to the particular independent variable (Table 6).

Table 6: Association between Water, Sanitation and Hygiene and *E. coli* load

Variable	OR	P-value (95% CI)	AOR	P-value (95% CI)
Hand wash				
Sometimes	0.47	0.54 (0.04, 5.26)	0.65	0.74 (0.05, 8.25)
Toilet distance				
> 10 metres	1.11	0.92 (0.14, 8.82)	1.94	0.58 (0.18, 20.42)
Animals present				
No	1.04	0.97 (0.14, 7.76)	0.56	0.62 (0.06, 5.58)
Collection time				
> 30 minutes	3.53	0.32 (0.29, 41.94)	3.86	0.31 (0.29, 51.67)
Water source				
Well	0.98	0.99 (0.14, 6.93)	0.18	0.31 (0.01, 4.75)
Pipe	1	-	-	-

OR - Odds Ratio, AOR - Adjusted Odds Ratio, CI - Confidence Interval, *Significant (p < 0.05)

CHAPTER FIVE

5.0 DISCUSSION

5.1 Observational and behavioural practices of households

A cross-sectional study was conducted to assess the quality of drinking water stored at the household level (point-of-use) in five selected rural towns in the Akuapem South District of Ghana. It was found that less than one per cent (0.9%) of surveyed households in the study area use unimproved water source, with the majority sourcing their water from improved sources (borehole, protected wells and pipe). However, analysis of the questionnaire showed that close to two-thirds of households (67%) had to make a round trip of more than thirty (30) minutes to collect water, a phenomenon that increases the risk of contamination of water, thereby, affecting the quality (United Nations Children Fund & World health Organisation, 2017) to collect water as the water sources are strategically positioned to cater for all members of the community. Water sources which are outside the homes of households limit the volume of water available for use as it must be carried over a long distance to be stored, increasing the risk of contamination.

Although most households (86.1%) stored water in a covered storage vessel, most respondents (98.6%) withdrew water from storage vessels unhygienically. Instead of withdrawing water from the vessel with a long-handled pail or fixing a spigot or tap on the vessels to regulate the flow and maintain the safety of stored water, respondents used cups, which could introduce contaminants into the water. This factor could have contributed to the water contamination as observed in the water quality analysis where *E. coli*, was detected in 80% of household water samples whereas, all (100%) contained

TTC. Studies (Guo *et al*., 2017) have shown that water storage vessels that are equipped with spigots, taps or other mechanisms which prevent contact from human hands with stored water have a low level of water contamination at the point of use. Measures including regular supply of pipe-borne water and education of community members on hygienic water handling practices must therefore be introduced in the study area in order to improve the quality of water in the households (UNICEF & WHO, 2019; WHO, 2014). A small minority of households (6.5%) notwithstanding, treat their drinking water by boiling which in itself is not sustainable to embark on as a result of its economic cost if one has to treat large volumes of water by this method, considering the fact that these are rural dwellers with low income. In addition, almost all households (99.1%) use the stored water for other domestic purposes including cooking and bathing, which may introduce more contaminants into the water by the continuous unsafe methods of water withdrawal from the storage vessels as described above.

Hand washing with soap, which has been proven to prevent contamination of water by majority of disease causing bacteria (Guo *et al*., 2017; WHO, 2014) is not a common practice among households in the study area. Findings of this study showed that only 3.2% of households wash their hands regularly before fetching water from the vessels to drink or use for cooking and other purposes. The bulk majority (96.8%) however, did not adopt proper water handling practices. This poor water handling and hand hygiene practices could be a major reason for the high levels of contamination observed in the stored water in most (80%) of the households surveyed as depicted in the water analysis. Findings of the study also showed that households keep water for at least one (1) week in storage vessels before cleaning. Since the method for withdrawal of water from the storage vessels allow contamination, keeping water for long periods in storage vessels would increase the level of exposure to contaminants and the risk of infection by water-borne diseases (Stephens, 2002; Boateng, Adam & Tia-Adjei, 2013).

5.2 Bacteriological quality of household water

For a drinking water to be accepted as safe, *E. coli* and TTC must not be detected (WHO, 2011). The main source of pathogen contamination in water are faecal matter from both human and animal faeces (UNICEF & WHO, 2019). From the water samples analysed in the laboratory, the mean *E. coli* counts from the water samples taken ranged from zero (absent) to as high as 300 cfu/100 mL. The finding that *E. coli* count was higher in household (point of use) drinking water as observed in this study, confirms that the most likely causes of contamination for household drinking water as observed in this study were poor water handling and hygiene practices at the point of use and possibly during transportation from the sources of collection. Similar studies conducted by Mertens *et al*. (1990), Lechtenfeld (2012), Engebretson (2014), GSS (2014), Johnston (2014) and Wright *et al*. (2004) showed that contamination of water with *E. coli* at the point of use (household), increased with increasing travel distance from the point of collection (source water) and poor handling practices in households. The multivariate logistic regression of the association between *E. coli* load in household drinking water and time of transportation for collection of water indicates that *E. coli* load increases by as much as 3.86 cfu/100 mL if households spend more than thirty (30) minutes to collect water from source even though it was not statistically significant ($p < 0.31$). This finding is in line with those of Gundry *et al*. (2004), Engebreton (2014), Awuah, Nyarko and Owusu (2008) and thus emphasizes the need to increase the accessibility of households to treated water and education of community members on good water handling and hand hygiene practices.

In terms of sanitation, it was shown that the farther a toilet facility is from households, the more the likelihood of water contamination. This is probably because the farther away toilet facilities are from households, the more difficult it is to access, leading to increased open defecation and a higher tendency for contamination of household water. Similar studies conducted elsewhere (Jones, 2010; Boadi & Kuitunen, 2005) corroborates this finding. Additionally, households which did not keep animals in their homes were less likely to contaminate their stored water (AOR: 0.56; $p < 0.62$) than those which did. The high *E. coli* levels (77.7 cfu/ 100 mL ± 99.9) in stored water as determined in this study was consistent with the responses from the households interviewed regarding water handling practices. The responses from majority of households indicated that water, sanitation and hygiene practices were poor. For instance, many households dip unclean cups, bowls and hands in stored water in order to draw water, coupled with the fact that many do not clean their water storage vessels regularly, in addition to using stored water for other purposes apart from drinking, more so when many households keep animals in the house which defecate indiscriminately in the immediate surroundings. These practices have the potential of contaminating stored water at the point of use, with faecal matter. In addition, water treatment was not a practice adopted by the households at the point of use so stored water is always under threat from being contaminated by hazardous environmental contaminants. Only a few households (6.5%) treat their water before drinking, with the majority (93.5%) drinking without treatment. This finding is similar to that of Chaudhary *et al.*, (2015) who reported that although clean water was important in reducing diarrhoea, just few households treated their water before drinking. Another study conducted by Merga and Alemayehu (2015), showed that lack of knowledge was the main challenge preventing households from treating their water correctly. Even though respondents' knowledge on safe water handling practices was not assessed in this study, other studies (Rainy & Harding, 2005; Merga & Alemayehu, 2015; Daniel, 2015; Guo *et al*., 2017) have shown that knowledge increases with practice. In view of this, the unsafe water handling behaviour as observed among the households, was probably because of inadequate knowledge about the practice and its importance to health. It can therefore not be over-emphasized that education on the link between safe water handling practices, sanitation and hygiene to health are of utmost importance to protect stored water from recontamination at the household level in the study area.

5.3 Physico-chemical quality

The physico-chemical parameters analysed in household drinking water in the study area were generally within the acceptable limits per the WHO guidelines on drinking water quality. However, whereas, the chemical parameters were all within limit, some physical parameters in some towns did not meet the required specification. For instance, the pH measured in a number of towns were below the pH requirement range of 6.5-8.5. Two towns, Gyankama and Konkonuru for example had mean pH levels of 5.5 and 5.6 respectively. This makes the water from these two towns slightly more acidic compared to the other three towns with mean pH of 7.5, 7.4 and 6.5 for Ahwerase, Brekusu and

Kitase respectively. This finding is comparable to that of Herath *et al*. (2012), who reported pH values in bottled water below the recommended WHO guideline. Although the WHO guideline for pH is meant to reduce corrosion of metals in distribution pipes and thus may not be directly relevant to household water, continuous use of acidic water may increase the risk of contamination with copper and iron that may leach from distribution pipes into water in municipal water supply hence, must be monitored periodically (WHO, 2012; Fisher *et al*., 2015).

Turbidity indicates the presence of pathogenic microorganisms and may therefore be an effective pointer to hazardous substances in many water supply systems. High turbidity in filtered water points to poor pathogen removal which may lead to water-borne diseases when consumed (WHO, 2017). The mean turbidity (1.24±0.31 NTU) recorded in this study was in compliance with the WHO maximum contaminant level of (≤ 5). In addition, the mean turbidity among selected towns were not statistically different. A study conducted in Sierra Leone which looked at sachet and raw water among others were all within acceptable levels (Fisher *et al*., 2015).

Electrical Conductivity (EC), which is a measure of the inorganic mineral ions in water and is also used as an indicator for high total dissolved solids (TDS), does not have any direct health concern (WHO & UNICEF, 2012). Notwithstanding, it is commonly accepted that drinking water becomes unpleasant and may be rejected by consumers at concentrations above 1400 μS/cm, equivalent to TDS of 1000 mg/L (WHO, 2011a). At such elevated levels the water becomes salty, affecting the taste as a result of the high mineral salts content, leading to its rejection. The mean EC (341±183.9 µS/cm) and TDS (216.8±115.6 mg/L) measured in the study area were within the WHO recommended limit (≤1400 µS/cm and 1000 mg/L respectively). This is similar to findings from Seshie-doe, (2017) who measured EC in ground water which were within the required accepted level. The TDS levels also corroborate a study by Fisher *et al*. (2015), who reported TDS values in sachet and raw water all within acceptable limits.

5.4 Limitations of the Study

Due to time and resource constraints, only 30 different water samples from households could be analysed for bacteriological and physico-chemical parameters.

Responses to questions in the questionnaires as provided by the respondents could not be ascertained in terms of accuracy and partiality or biases.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The findings of this study indicate that household water is heavily contaminated with bacteria mostly due to the poor water handling and insanitary conditions under which water is stored, although majority of households in the study area have access to an improved source of water (borehole).

There was a relationship between water, sanitation and hygiene practices and water quality at the household level (point of use). Because water sources are farther away from households, there is an increased risk of water deterioration as households have to travel long distances to transport water to their homes for storage and use.

Furthermore, the findings showed that water, sanitation and hygiene practices are good predictors of faecal contamination in household water, as confirmed in the water quality test. Putting everything in context, these findings emphasize the requirement for interventions within households, including adoption of water treatment, safe water handling, improved storage and proper hand hygiene practices to guarantee safe drinking water, among households.

6.2 Recommendations

In the short-term, health education on the link between water, sanitation and health must be promoted, in addition to adopting good sanitation and hygiene practices to reduce contamination of stored household water.

Households must keep separate vessels for storing drinking and domestic water to minimize contamination due to multiple use of the stored water.

In the medium term, households must be encouraged and supported to effectively treat their stored water by adopting efficient and cost-effective methods, before using.

In the long term, government should show more effort in extending piped water to the premises of households as piped water into dwellings is the most effective means of maintaining the quality of drinking water.

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APPENDICES

Appendix I: Timeline and Budget

Timeline:

Period	**Activity**
Sept, 2018	Submission of research topic
Sept, 2018	Submission of objectives
Sept, 2018	Submission of problem statement and conceptual framework
Sept – Oct, 2018	Writing of introduction and literature review
Oct, 2018	Proposal presentation
Oct – Nov, 2018	Submission of full proposal for ethical review and clearance
Nov, 2018 – Jan, 2019	Planning of field work
Jan – Feb, 2019	Sample collection
Mar – April, 2019	Laboratory analysis, Data analysis and write-up
May – Jun, 2019	Submission of draft dissertation to supervisor
Jul, 2019	Submission of final dissertation

Budget:

Item	**Amount (GHC)**
Laboratory Analysis	5000
Recruitment and Training of Research Assistants	500
Stationery and Secretarial Services	300
Communication	200
Transportation	500
Miscellaneous	200
Total	**6700**

Appendix II: Questionnaire

SCHOOL OF PUBLIC HEALTH
COLLEGE OF HEALTH SCIENCES
UNIVERSITY OF GHANA - LEGON

HOUSEHOLD QUESTIONAIRE

Title: Assessing the Quality of Household Drinking Water in Selected Communities in the Akuapem South District.

This questionnaire is part of a research by **Kofi Asare Lartey** towards the award of a Master of Public Health degree from the University of Ghana. The research is aimed at determining the quality of household drinking water in selected communities in the Akuapem South District of the Eastern Region of Ghana. You may help us complete the questionnaire by answering a few questions below. Your participation is vital to the success of this study. Be assured that any information you provide will be confidential as it will be reported in the form of statistical summary.

For further questions or concerns, you may contact the principal investigator on the following:

Name: **Kofi Asare Lartey**
Phone: 0243322291
Email: okfantasy@yahoo.com

Thanks you for cooperation.

Interview Date---------------------------- District: Akuapem South

Interviewer Name: --- Town/Village: ------------

(All information in this questionnaire is confidential).

NB: PLEASE DO NOT DISCARD THIS QUESTIONNAIRE. GIVE IT BACK TO THE COORDINATOR EVEN IF IT IS DAMAGED.

Instruction: kindly complete the questionnaire by ticking [√] the appropriate number that corresponds to the answer.

Serial Number……………………… Date……………………

Village /Town……………………… District: Akuapem South

No.	Question/Item	Response [√]
Demography		
1.	Sex of Respondent	1. Male [ ] 2. Female [ ]
2.	Age	1. 18 – 29 [ ] 2. 30 – 39 [ ] 3. 40 – 49 [ ] 4. 50 and above [ ]
3.	Level of Education	1. Basic [ ] 2. Secondary [ ] 3. Tertiary [ ] 4. None [ ]
4.	Occupation	1. Farming [ ] 2. Trading [ ] 3. Gov't. Employed [ ] 4. Self Employed [ ] 5. Unemployed [ ] 6. Others [ ]
5.	Number of persons in household	1. ≤ 3 [ ] 2. 4 and above [ ]

Source of Water, Handling and Storage		
6.	What is the source of your drinking water?	1. Borehole [ ] 2. Well [ ] 3. Pipe [ ] 4. Others [ ]
7.	Is the water obtained from more than one source?	1. Yes [ ] 2. No [ ]
8.	How long does it take to collect water from the source?	1. ≤ 30 minutes [ ] 2. > 30 minutes [ ]
9.	Which type of container do you use for water collection?	1. Bucket [ ] 2. Jerry Can [ ] 3. Wide-mouthed Pan [ ]
10.	Which type of container is used for storing water in the house?	1. Drum [ ] 2. Barrel [ ] 3. Tank [ ]
11.	What is the storage container made of?	1. Plastic [ ] 2. Metal [ ] 3. Clay [ ]
12.	How often do you clean the storage container?	1. Weekly [ ] 2. Monthly [ ] 3. Quarterly [ ]
13.	How is water drawn from the container for usage?	1. Pouring [ ] 2. By cup [ ] 3. Spigot [ ]
14.	Is the water storage container used for storing any other liquid or material?	1. Yes [ ] 2. No [ ]
15.	Is the water storage container kept at ground level?	1. Yes [ ] 2. No [ ]
16.	Does the water storage container have lid or cover in place?	1. Yes [ ] 2. No [ ]

17.	Is the storage container cracked or leak?	1. Yes [ ] 2. No [ ]
Hygiene Practices		
18.	Is the area around the storage container clean?	1. Yes [ ] 2. No [ ]
19.	Is there a latrine or toilet facility within the house?	1. Yes [ ] 2. No [ ]
20.	How close is the latrine or toilet facility to the storage container?	1. ≤ 10 meters 2. > 10 meters
21.	Do you keep any animal in the house?	1. Yes [ ] 2. No [ ]
22.	Is the water from the container also used for washing or bathing?	1. Yes [2. No [ ]
23.	Do you wash your hands before fetching water from the storage container?	1. Yes [ ] 2. No [ ] 3. Sometimes [ ]
Water Treatment Method		
24.	Do you treat your water before drinking?	1. Yes [ ] 2. No [ ]
25.	Which treatment method or technology do you use?	1. Boiling [ ] 2. Filtration [ ] 3. Chlorination [ ] 4. Others [ ]

Appendix III: Ethical Approval Letter

GHANA HEALTH SERVICE ETHICS REVIEW COMMITTEE

In case of reply the number and date of this Letter should be quoted

MyRef. GHS/RDD/ERC/Admin/App 19/149
Your Ref. No.

Research & Development Division
Ghana Health Service
P. O. Box MB 190
Accra
GPS Address: GA-050-3303
Tel: +233-302-681109
Fax + 233-302-685424
Email: ghserc@gmail.com
5th May, 2019

Kofi Lartey Asare
University of Ghana
School of Public Health
Legon

The Ghana Health Service Ethics Review Committee has reviewed and given approval for the implementation of your Study Protocol.

GHS-ERC Number	**GHS-ERC 036/04/19**
Project Title	Assessing the Quality of Household Drinking Water in Selected Communities in the Akuapem South District.
Approval Date	5th May, 2019
Expiry Date	4th May, 2020
GHS-ERC Decision	**Approved**

This approval requires the following from the Principal Investigator

- Submission of yearly progress report of the study to the Ethics Review Committee (ERC)
- Renewal of ethical approval if the study lasts for more than 12 months,
- Reporting of all serious adverse events related to this study to the ERC within three days verbally and seven days in writing.
- Submission of a final report after completion of the study
- Informing ERC if study cannot be implemented or is discontinued and reasons why
- Informing the ERC and your sponsor (where applicable) before any publication of the research findings.
- Please note that any modification of the study without ERC approval of the amendment is invalid.

The ERC may observe or cause to be observed procedures and records of the study during and after implementation.

Kindly quote the protocol identification number in all future correspondence in relation to this approved protocol

SIGNED...
DR. CYNTHIA BANNERMAN
(GHS-ERC CHAIRPERSON)