

**HOUSEHOLD WATER TREATMENT TECHNOLOGIES FOR  
MICROBIAL REMOVAL IN KABALE DISTRICT,  
SOUTHWESTERN UGANDA**

**ALEX SATURDAY**

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the Award of the Degree of Master of Science (Integrated  
Watershed Management) in the School of Pure and Applied  
Sciences, Kenyatta University.**

**JUNE, 2016**



**DECLARATION**

This thesis is my original work and has not been presented for a degree or any other award in any other university.

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## **DEDICATION**

This thesis is dedicated to God almighty, my father, Mr. Robert Musingize, my mother Mrs. Winnie Kinaheirwe, my lovely friend Ms. Savious Owamani, and my lovely sisters and brothers, friends and all young scholars.

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## OPERATIONAL DEFINITION OF KEY TERMS AND CONCEPTS

**Household water treatment technologies:** Household water treatment technologies are methods employed for purposes of treating and storing drinking water at household level. Sikod *et al.* (2015) defined household water treatment and storage as methods employed for purposes of treating water in the home. Household water treatment technologies are also referred to as point-of-use water treatment technologies. The technologies encompass a range of options that enable people or communities to remove or inactivate pathogenic microbes in drinking water. In Kabale District, the technologies include; boiling, biosand filtration, let it stand and settle, application of WaterGuard and application of aqua safe tablets.

**Improved drinking water source:** WHO and UNICEF (2012) define improved drinking water as ones that are by nature of their construction or through active intervention protected from outside contamination, and in particular from contamination with faecal matter. Improved drinking water sources include; piped water on premises, yard or plot, standpipes, protected springs, protected boreholes and protected dug wells (WHO & UNICEF, 2011). Other improved drinking water sources are ones except piped drinking water source on the premises that are by nature of their construction protected from outside contamination especially faecal matter (WHO & UNICEF, 2011). In Kabale District, improved drinking water sources are piped water into the dwelling, stand pipes, protected springs and protected boreholes.

**Unimproved drinking water sources:** WHO and UNICEF, (2011) defined unimproved drinking water sources as ones that are by nature of their construction, location and management unprotected from outside contamination. Such drinking water sources include; unprotected springs, carts with small tanks, unprotected dug wells, tanker trucks, and surface waters such as rivers, dams, lakes, pond and stream (WHO & UNICEF, 2011). In Kabale District unimproved drinking water sources include; unprotected dug wells, unprotected springs, and surface waters such as stream water, ponds and water direct from the lakes.

**Safe drinking water:** UNICEF and WHO (2012) defined safe drinking water as water with microbial, chemical and physical characteristics that meet WHO drinking water quality guidelines or national standards for drinking water quality. In this case, safe drinking water refers to that water with bacteriological characteristics that meet national and international drinking water quality standards. According to UNBS, (2008), safe drinking water should have no detectable total coliforms or *Escherichia coli* per 100 ml of a given drinking water sample.

**Microbial removal:** In this case, microbial removal refers to eliminating total coliforms from drinking water.

**A household:** A household is defined as persons who have eaten and slept under the same roof for at least five days of the week (Valerie, 2010).

**Log<sub>10</sub> reduction:** This is a mathematical term that shows the relative number of live microbes eliminated from a water sample after water treatment or disinfection.

**Safe water sources:** Water sources with bacteriological characteristics that meet national and international source drinking water quality standards.

## LIST OF ACRONYMS AND ABBREVIATIONS

APHA	American Public Health Association
AT	After Treatment
B.C <sub>a</sub>	Bacteria Count After Treatment
B.C <sub>b</sub>	Bacteria Count Before Treatment
BC	Bacterial Count
BT	Before Treatment
CFU	Colon Forming Units
DAAD	German Academic Exchange Service
DWD	Directorate of Water Development
E.C <sub>LR</sub> (%)	Percentage <i>Escherichia Coli</i> Removal
E.C <sub>LR</sub>	<i>Escherichia Coli</i> Log <sub>10</sub> Reduction
E.C <sub>a</sub>	<i>Escherichia Coli</i> Concentration after Treatment
E.C <sub>b</sub>	<i>Escherichia Coli</i> Concentration before Treatment
GFS	Gravity Flow Schemes
GoU	Government of Uganda
HWT	Household Water Treatment Technologies
IWRM	Integrated Water Resources Management
KDLG	Kabale District Local Government
MDG	Millennium Development Goals
MPED	Ministry of Finance, Planning and Economic Monitoring

NaDCC	Sodium dichloroisocyanurate
ND	None Detected
NWSC	National Water Sewerage Corporation
SDG	Sustainable Development Goals
$T/C_{LR}$	Total Coliforms $\text{Log}_{10}$ Reduction
$T/C_{LR} (\%)$	Percentage Total Coliforms Removal
$T/C_a$	Total Coliforms before Treatment
$T/C_b$	Total Coliforms before Treatment
UBOS	Uganda Bureau of Statistics
UNBS	Uganda National Bureau of Standards
VATs	Village Health Teams
WHO	World Health Organization

## ABSTRACT

Health problems associated with the consumption of untreated drinking water is one of the greatest concerns in Kabale District inspite of government's efforts to provide safe drinking water to the people. Household water treatment and safe storage has been shown to be an effective means of reducing health problems associated with unsafe drinking water. The purpose of this study was to examine household water treatment technologies (HWT) and evaluate their ability to improve microbial quality of drinking water. The specific objectives of the study were to: (i) evaluate the different water sources, household water treatment technologies, and storage options of household drinking water, (ii) establish whether the sources of drinking water influence the type of water treatment technologies used at household level, (iii) determine whether there is significant difference between bacterial counts in household drinking water samples before and after treatment, and (iv) evaluate bacteriological effectiveness of household water treatment technologies used under laboratory conditions. The study employed both analytical and descriptive research designs utilizing mixed methodologies. A multistage sampling technique was used to select 205 respondents, who were used to obtain socio-economic data, using semi-structured questionnaires. Drinking and source water samples were collected from households and sources of drinking water reported with high pathogenic bacteria concentration respectively for *Escherichia coli* and total coliforms analyses. World Health Organization (WHO) drinking water quality guidelines were used to categorize drinking water in terms of risk level category. Statistical package of social sciences was used for data analysis. Chi square test was used to test whether sources of drinking water influenced the type of water treatment technologies used at household level. A paired sample T-test was used to compare mean difference between bacteria counts in household drinking water samples before and after treatment. A one way ANOVA was used to compare mean differences in bacteria reductions by different HWT in experiment test water samples. Descriptive statistics were used to analyze data. Majority respondents (61.5%) were using springs as their sources of drinking water. Of 46 household treated water samples, 17.4% and 45.7% of water samples fell in no risk category (0 CFU/100 ml) for total coliforms and *Escherichia coli* respectively. Of 20 experiment treated water samples, 40% and 73% of samples fell in no risk category (0 CFU/100 ml) for total coliforms and *Escherichia coli*, respectively. Treatment by application of WaterGuard tablets achieved highest total coliforms removal with 99.5% (1.9 log<sub>10</sub>), whereas WaterGuard tablets, biosand filtration method, and aqua safe tablets achieved complete removal of *Escherichia coli* (100%) under laboratory conditions. Chi square test yielded no significant relation between drinking water sources and the type of HWT used at household level ( $P < 0.05$ ). The paired samples T-test showed a significant difference between bacteria counts before and after treatment. Significant differences were observed between mean bacteria reductions in experiment test water samples. Spring water in Kabale District was found unsafe to drink unless treated. Effective water treatment products such as WaterGuard and aqua safe tablets should be promoted at local level. Local people should always be involved in simple household testing to reduce doubts on microbial efficiency of newly introduced HWT.

## CHAPTER 1: INTRODUCTION

### 1.1 Background to the study

Lack of access to safe drinking water contributes significantly to the global human health burden and death resulting from infectious waterborne diseases. Lothrop *et al.* (2015) noted that increased contaminant guideline exceedances in water supplies exposes people especially in rural areas to a risk of long-term negative health outcomes, adding to their rural health disparities. Globally, unsafe drinking water is a leading cause of preventable diseases, especially among children in developing countries where there is inadequate sanitation. Current figures indicate that more than 700 million people globally lack access to improved water sources (WHO & UNICEF, 2014).

Sobsey *et al.* (2008) revealed that household water treatment technologies have emerged as means to empower the local people and communities without access to safe drinking water at home. Such technologies include; filtration, boiling, solar disinfection and chemical disinfection among others. UNICEF and WHO (2011) reported that household water treatment and safe storage is one option for improving drinking water quality within the home, more especially where water handling and storage is necessary and recontamination is a real risk between point of collection and point of use. Access to a distant water source only, unreliable piped supplies, reliance on surface waters (ponds, lakes, streams and rivers) and unprotected springs, boreholes and dug wells are crucial factors that make household water treatment and storage a necessity (WHO & UNICEF, 2011).

According to WHO (2010), Sub-Saharan Africa is most remarkably and disproportionately affected by lack of access to safe drinking water. Approximately 327 million people without access to safe drinking water live in Sub-Saharan Africa (WHO & UNICEF, 2010, 2014). The SDG 6, target 3 aims at reducing water scarcity by protecting water sources (Costanza & Kubiszewski, 2014). Paradoxically, people still drink unsafe water inspite of improved access to safe drinking water.

Drinking water can be contaminated at the source, in the distribution system, during collection, transportation and storage. Even if SDG 6 is achieved, millions of households in developing countries will still remain at risk of preventable waterborne diseases until household water treatment interventions are promoted on a large scale. Waterborne diseases include diarrhea and cholera. Indirect health effects such as neurological syndromes, reactive arthritis, malnutrition, and arrested growth and development, are also attributed to consumption of unsafe drinking water (Sobsey *et al.*, 2008).

Access to safe drinking water sources in Uganda significantly increased from 54% in 2001 to 76% in 2015 because of high level investment in water sector by the government and other development partners. However, the burden of waterborne diseases, child mortality and morbidity remain a significant challenge (WHO & UNICEF, 2015). UBOS (2012) reported that 23%, and 14% of 1,096 children under the age five countrywide and in southwestern part of the country, respectively had diarrhea disease before 2012 demographic health survey. The report further indicated

that child mortality rate was 90 deaths per 1,000 live births. Most of these deaths were caused by diarrheal disease as a result of unsafe drinking water.

In Kabale District, 81% of households have access to safe drinking water sources (DWD, 2010). In addition, 82% and 73% of households in rural and urban areas respectively have access to safe drinking water sources (DWD, 2010). Due to recontamination of drinking water during distribution, transportation, and storage, there is the likelihood of increasing population without access to safe drinking water than the reported. It is therefore necessary to establish drinking water sources, HWT used, reasons for use of different HWT, and microbial removal efficiency of HWT used in Kabale District.

## **1.2 Statement of the problem**

In Kabale District, water is used for numerous activities such as livestock watering, cooking, bathing and drinking. Human beings defecate and urinate near these water sources as well (Personal Observation). Consequently, this water may be contaminated with pathogenic bacteria, for example, *Escherichia coli*, *Salmonella typhi*, *Shigella* spp., and *Yersinia enterocolitica* that cause waterborne diseases such as diarrhea, cholera, typhoid and among others. Health problems associated with drinking untreated water is one of the most significant concerns in Kabale District.

The Ugandan government had since 1990s made efforts to provide safe drinking water to the people through national water and sewerage corporation (NWSC), and gravity flow scheme projects (GFS). In spite of all these efforts, the prevalence of



water related illnesses remains high. In southwestern Uganda, UBOS (2012) revealed that 18.8% of children had diarrhea cases before 2012 demographic health survey. Such findings raise suspicion of possible contamination of drinking water at household level. This study therefore, seeks to inform the safety of HWT for bacterial removal from drinking water in Kabale District, southwestern Uganda.

### **1.3 Justification of the study**

Generally, there is inadequate data on household water treatment technologies under laboratory conditions to provide a solid scientific base to speed-up and scale-up their implementation in Kabale District. Safe drinking water can leave water treatment plants to supply points. However, sub-standard water distribution systems, illegal connections to the distribution system, pressure changes due to power outages, and other disruptions often lead to the introduction of faecal contamination. Thus, microbiologically contaminated water is delivered to consumers' taps or collection points (Clasen *et al.*, 2008; Sobsey *et al.*, 2008). Waterborne disease outbreaks in Kabale District are relatively common, yet access to safe drinking water is significantly high. Thus, establishing microbial quality of water from the sources and from households is strongly encouraged. Methods of water collection and storage may affect the quality of drinking water. Therefore, examining different water storage options used at household level is justifiable. Numerous research studies on household water treatment have been undertaken outside Uganda and have shown a significant improvement on microbial quality of drinking water and reduction in waterborne diseases such as diarrhea. Household water treatment has been shown to

be an effective means of improving household drinking water quality and reducing diseases associated with unsafe drinking water (Sobsey 2002). Additionally, a systematic review by different researchers in 2005 concluded that diarrhoea can be reduced by 39% through household water treatment and safe storage (Fewtrell *et al.*, 2005). According to “The networks,” (2011), Ugandan government acknowledged her early stage in use of household water treatment technologies and stressed the need for immediate research into the new development. Evaluating the existing water treatment technologies for microbial removal from drinking water at household level is crucial.

#### **1.4 Research questions**

- i. What are the water sources, household water treatment technologies, and storage options of household drinking water in Kabale District?
- ii. Does the source of drinking water influences the type of water treatment technology used at household level?
- iii. Is there any significant difference between bacterial counts in household drinking water samples before and after treatment?
- iv. What is the bacteriological effectiveness of household water treatment technologies used under laboratory?

#### **1.5 Research hypotheses**

This present study tested the following hypotheses:

- i. The source of drinking water does not influence the type of water treatment technology used at household level.

- ii. There is no significant difference between bacteria counts in household drinking water samples before and after treatment.
- iii. There are no significant differences between mean bacteria reductions by different HWT under laboratory conditions.

## **1.6 Objectives of the study**

### **1.6.1 General objective**

To examine household water treatment technologies in use and evaluate their ability to improve the microbial quality of drinking water at household level in Kabale District, southwestern Uganda.

### **1.6.2 Specific objectives**

This study was addressed by the following specific objectives:

- i. To evaluate the different water sources, household water treatment technologies, and storage options of household drinking water.
- ii. To establish whether the sources of drinking water influence the type of water treatment technologies used at household level.
- iii. To determine whether there is significant difference between bacterial counts in household drinking water samples before and after treatment.
- iv. To evaluate bacteriological effectiveness of household water treatment technologies used under laboratory conditions.

### **1.7 Significance of the study**

Results of this study will serve to enlighten water users' safety about waterborne diseases. The study results will provide information that aid in formulating policies on safe drinking water in Kabale District. The results of this study will assist the relevant authorities in designing appropriate mitigation measures to ensure that domestic water supplies are protected. Water quality data will enable policy makers to decide and implement best practices that protect human beings from dangers resulting from drinking contaminated water. The study has added on to the existing literature in IWRM and with reliable performance data under laboratory conditions. This will speed-up and scale-up the implementation of household water treatment technologies in Kabale District.

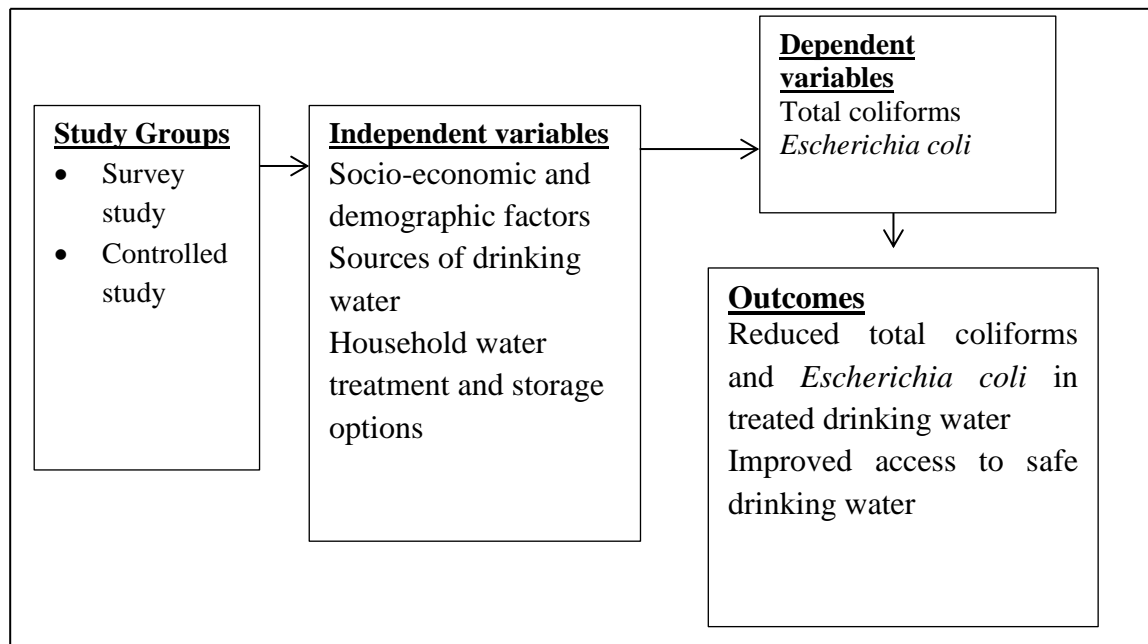
### **1.8 Scope and limitation of the study**

The study was conducted in Kabale District, southwestern Uganda. The study identified and described the different sources of drinking water and household water treatment and storage option. The study established the reasons for use of different household water treatment technologies and evaluated bacteriological effectiveness of household water treatment technologies used in Kabale District. During field study visits, household heads or a household member above 18 years of age were interviewed. Household water samples were collected from households when reported available. Experimentation was done with water samples collected from water sources with reported high total coliforms and *Escherichia coli* concentration during field study visits. During the field study surveys, it was not easy to get hold of

respondents as most of them had other commitments. In Rwamucucu and Nyamweru sub counties, most of the people were always busy with their farm activities until late evening. This made us walk long distances in search for other respondents to interview.

### **1.9 Conceptual framework**

The conceptual framework (Figure 1.1) was used to assess the effectiveness of household water treatment technologies for microbial removal. Total coliforms and *Escherichia coli* in tested water samples from selected households were used as dependent variables. A number of household factors in the area of study determined the level of total coliforms and *Escherichia coli* in both treated water and untreated source water samples. These factors included; socio-economic and demographic factors, sources of drinking water, HWT used, water handling practices among others. These factors were used as independent variables. Socio-economic and demographic factors included; age, gender, household size and, level of education and level of income. Sources of drinking water included; public stand taps, water springs, shallow wells, boreholes, rainfall, piped water in dwelling, streams and rivers. HWT included; application of WaterGuard tablets, application of aqua safe tablets, boiling, filtration and let it stand and settle method. Water storage options were plastic jerry cans, clay pots and plastic buckets. Water handling practices were water collection, transportation, storage and all those activities that may involve hands into direct contact with drinking water. Reduced total coliforms and *Escherichia coli* herein refer to reduction in CFU level in treated drinking water.



**Figure 1.1: Conceptual framework for effectiveness of HWT (Modified after Valerie, 2010).**

## **CHAPTER 2: LITERATURE REVIEW**

### **2.1 Introduction**

This chapter highlights the various studies related to the current research, gaps emanating from these works, and how the present study contributes to fill some gaps identified. Literature review for this study is done thematically under the following sections; sources of drinking water, household water treatment and storage options, reasons for use of different HWT and indicator organisms for microbial drinking water contamination.

### **2.2 Sources of drinking water**

According to WHO (2004), water is considered safe to drink as long as it does not cause any significant health risks over life time consumption. According to WHO and UNICEF (2008), drinking water sources are classified into three main categories; piped water on premises, other improved drinking water sources, and unimproved drinking water sources. Components of each category are as described in the subsequent sections.

#### **2.2.1 Piped water on premises**

Piped water connection on user's premises, yard or plot is the ideal service, since it provides the most convenient supply and has positive health impacts (WHO & UNICEF, 2011). Globally good progress has been made in the use of piped drinking water on premises. A report by WHO and UNICEF (2008) revealed that 2.5 and

1.1 billion people in urban and rural areas respectively have access to piped drinking water connection on their premises.

### **2.2.2 Other improved drinking water sources**

The other improved water sources are protected shared community sources such as public taps, rainwater harvesting, protected dug wells, protected springs and boreholes (Bain *et al.*, 2014; UNICEF & WHO, 2011). Since 1990, use of other improved drinking water sources has substantially increased. In Southern Asia, the population using other improved drinking water sources increased from 54% to 65 % between 1990 and 2008 (UNICEF & WHO, 2011). In Sub-Saharan Africa, use of other improved water sources increased from 33% to 42% between 1990 and 2008 (UNICEF & WHO, 2008, 2011). The study did not establish the characteristics of other improved drinking water sources and the possible sources of contamination. The current study intends to fill these gaps with information.

### **2.2.3 Unimproved drinking water sources**

Unprotected springs, unprotected dug wells, tanker trucks, and surface waters such as rivers, dams, lakes, pond and streams are considered “unprotected” drinking water sources (Bartram *et al.*, 2014; UNICEF & WHO, 2008). WHO and UNICEF (2008) further revealed that 13% of the world’s population without access to safe drinking water sources gets drinking water from unimproved sources. Sub-Saharan Africa has the largest population using unimproved water sources, though its figures dropped from 51% in 1990 to 42% in 2006 (WHO & UNICEF, 2008). The study did not establish the characteristics of unimproved drinking water sources and the



possible sources of contamination. This research study seeks to fill these gaps with information.

### **2.3 Household water treatment and storage options**

Household water treatment technologies have been proved to be a sustainable solution for developing countries facing challenges in providing safe drinking water to their people (Clasen *et al.*, 2007; Fewtrell *et al.*, 2005). Sobsey (2002) found out that simple and relatively inexpensive HWT have the potential to substantially improve the quality of drinking water by reducing microbial counts and the risks of illness and death. Clasen *et al.* (2006) reported 60 to 90% reduction in the incidences of diarrheal diseases when an appropriate implementation of HWT was considered in communities which had no access to safe drinking water supplies.

In countries like Pakistan, Bangladesh, Nepal, India, Guinea Bissau, Mauritania, Sierra Leone and Egypt, household water treatment is largely limited to richer quintiles, whereas in Indonesia, Lao peoples Republic, Bosnia, it is lower in richer quintiles (UNICEF & WHO, 2011). Rosa and Clasen, (2010) reported that use of HWT is most common among countries within the Western Pacific WHO region with 66.8% and least common in the Eastern Mediterranean and Africa with 13.6% and 18.2% respectively.

In a study by Proto *et al.* (2014) on one-year surveillance of the chemical and microbial quality of drinking water shuttled from the main land (Naples, Campania, Italy) to the Eolian Islands indicates that water delivered to the islands met drinking

water quality standards. However, during summer when the demand for drinking water increased Eolian Islands population increased too, the quality of the distributed water decreased most likely due to either use of vessels that were not specifically built for drinking water supply or could have used older drinking water supply containers. Such results suggest an implementation of water treatment at household level to manage the potential risk of waterborne diseases more effectively.

## **2.4 Examples of household water treatment technologies and storage options**

Several studies have revealed that HWT such as boiling, filtration, chlorine addition, and solar disinfection are effective in microbial removal (Rosa & Clasen, 2010; UNICEF & WHO, 2011). Straining water through a cloth or letting it stand and settle, are not considered appropriate methods of HWT (UNICEF & WHO, 2011). However, these methods are used in some parts of the developing world.

### **2.4.1 Boiling method**

Boiling method is the oldest method used to remove pathogenic bacteria from drinking water at household level. WHO (2004) recommends bringing water to a rolling boil point temperature (100°C) to ensure any pathogenic bacteria in water are killed. Agrawal and Bhalwar (2009) found out that heating water to as little as 55°C for several hours has proved to dramatically reduce non-spore forming bacterial pathogens in drinking water. The overall use of boiling method in Western Pacific region is 58.7%, least in the Eastern Mediterranean region (4.0%), and Africa (4.5%), where Uganda takes a lead in use of the method with 39.8% followed by Zambia with 15.2% (Rosa & Clasen, 2010). The overall global use of other adequate

technologies such as chlorine is 5.6%, filtration is 4.3%, and solar disinfection is 0.2% (Rosa & Clasen, 2010). Brown and Sobsey, (2012) found out that boiling reduces the level of *Escherichia coli* by 98.5%. In addition, of all tested water samples, 44% never had any *Escherichia coli* at all. The study did not establish the reasons for use of boiling method of water treatment at household level, neither the effectiveness of other popular household water treatment technologies such as filtration, chlorination, and solar disinfection.

#### **2.4.2 Chlorination**

Chlorination is widely used means of water purification and very effective against most bacteria and some viruses (WHO, 2006). Examples of chemical products used for chlorination in the study area are; WaterGuard and aqua safe tablets. The effectiveness of chlorination depends on the correct dose of chlorine solution being added to the volume of water to be treated. After chlorine is added to water, it then is mixed and allowed to stand for 30 minutes before water is safe for consumption. However, chlorination is not effective in highly turbid water (Nath *et al.*, 2006).

A study by Boisson *et al.* (2013) reported that use of chlorine in treating water at household level significantly reduce faecal contamination and improves microbial quality of drinking water. However, the extent to which the population continues to regularly use chlorine to treat drinking water is not clear. A study by Levy *et al.* (2014) noted inconsistency of chlorination on microbial removal in a controlled setting and in household setting. According to Halder *et al.* (2014), chlorine was used to sanitize water transport and storage containers by 32% and 50% respectively

of all surveyed individuals in the department of Yoro in rural Honduras. The study did not quantify the percentage of total coliforms eliminated as a result of disinfection by chlorine.

### **2.4.3 Biosand filtration**

Biosand filters were introduced by a Canadian researcher with an important design change that allowed the technology to operate with only intermittent water flow (Clasen, 2009). Passion to use biosand filters by several NGOs such as Samaritan's Purse has led to it being distributed in over 24 developing countries around the globe. This growth and popularity is attributed to the fact that a biosand filter can be made out of local available materials and the containers are typically made of either concrete or plastic (Clasen, 2009).

Fiore *et al.* (2010) conducted a study on the performance of biosand filters in rural communities of southern coastal Nicaragua. The study found out that 45 of 199 households visited had discontinued the use of biosand filter method. The study did not establish the reasons for discontinued use of the method, causes of an increase in number of CFU in treated stored water based on scientific evidence, did not compare the effectiveness of biosand filter method with the other popular HWT.

A study by Mwabi *et al.* (2012) in rural communities of Southern Africa reported that biosand filters have the capacity to produce 0.81– 6.84 liters per hour, an indicator that it can produce approximately 25 liters per day, the recommended average water a person can use on average. The study also reports a reduction in

bacteria by 99% – 100% when using biosand filter. However, the study did not consider effectiveness of popular household water treatment technologies in southern Africa such as boiling, solar disinfection, let it stand and settle method among others. Furthermore, the study didn't establish the proportion of the people using household water treatment technologies in Southern Africa.

In a study conducted by Tellen *et al.* ( 2010), 154 households water samples were tested. The median CFU/100 ml of *Escherichia coli* from water source, filter spout and storage vessel were 313, 72, and 144, respectively. In addition, Tellen *et al.* ( 2010) reported 98% and 99% reductions in total coliform, fecal coliform and fecal *Streptococci* for traditional biosand filtration and improved biosand filtration, respectively. This study did not establish the reasons for the discontinued use of the of biosand filtration method, possible factors for increase in CFU in treated stored water based on scientific evidence.

#### **2.4.4 Solar disinfection (SODIS)**

Solar disinfection is a simple method used to improve the quality of household drinking water by using sunlight to inactivate pathogens. The method involves filling transparent plastic bottles with water and exposing them to full sunlight. Exposure times vary from 6 to 48 hours depending on the intensity of sunlight. Use of solar disinfection can inactivate 97% of bacteria and 99% of virus (UNICEF, 2008). Improving microbial quality of drinking water using solar radiation is well known to inactivate bacteria and its effectiveness depends on local conditions (Dessie *et al.*, 2014). Nalwanga *et al.* (2014) asserted that use of solar disinfection led to

satisfactory bacterial inactivation ( $\log_{10}$  reduction values  $>6$  units for 11 of 13 experiments. Rainfall and cloudy conditions were the factors responsible for incomplete inactivation of bacteria that was observed (Nalwanga *et al.*, 2014).

#### **2.4.5 Household water storage options**

Regardless of whether the collected or treated household water is initially of acceptable microbiological quality, it often becomes contaminated with pathogens of fecal origin during transportation and storage due to unhygienic storage and handling practices (WHO, 2014). Use of narrow-mouthed water storage vessels with hard cover or lid together with good hygiene practices reduce recontamination of drinking water by hands especially after boiling (WHO & UNICEF, 2011). Storing household drinking water in a covered container was associated with production of safer drinking water than storage in an uncovered container (Brown & Sobsey, 2012).

A research study by Adade *et al.* (2014) revealed that bacteria count in water stored in earthen pots water exceeded the World Health Organisation and Ghana Standard Board specified drinking water quality limits. Total coliforms ranged from 9 to  $5.84 \times 10^2$  CFU/100 ml with a mean of  $2.47 \times 10^2$  CFU/100 ml. Earthen pot stored drinking water from the various communities was contaminated due to unhygienic handling practices such as dipping of hands and utensils into the storage earthen pot. However, the study neither established the level of bacteria before it was stored nor established the reasons for using earthen pots than other water storage options. The current study intends to fill these gaps with information.

## **2.5 Reasons for use of different household water treatment technologies**

Several studies have reported various reasons for use of different water treatment technologies at household level. According to UNICEF and WHO (2011), the proportion of people using appropriate household water treatment technologies globally is relatively high (50%) especially where drinking water is piped into the dwelling. This indicates that users do not trust the quality of their tap water. In contrast, about 23% of people using water sources such as dug wells and unprotected springs do not use appropriate household water treatment technologies (UNICEF & WHO, 2011). Perhaps the justification behind this could be a combination of economic, social, educational and geographical reasons.

A research study by Green (2008), reports that both rural and urban households expressed their preference to traditional HWT since they are long lasting and durable. Time factor was ignored by many respondents though a few of them revealed their preference to some methods that required short time to treat drinking water. Urban respondents reported that technologies that require long treatment time are difficult and limit their use. Cost factor also influenced the decision to use different household water treatment technologies though it did not have significant impact in the rural areas. The study did not establish the proportion of people using different household water treatment technologies. The study intends to fill the identified gaps with information.

A research study by Kakulu (2012) reported that 25% respondents were ignorant about other forms of household water treatment technologies besides boiling method.

The study further noted that 20% and 19% of respondents attributed the use of boiling method to cost-effectiveness and microbial removal effectiveness respectively. Further, four out of five (80%) households reported that chlorine was effective in disinfecting drinking water, whereas six out of nineteen (33.3%) respondents favored a cloth to strain drinking water. The study did not determine the average level of colony forming units as per WHO guidelines for drinking water quality. This study intends to fill this gap with information.

## **2.6 Bacterial parameters**

This section outlines the parameters used to determine household water treatment efficiency, ease of analysis, some implications and responses related to finding a positive sample. Table 2.1 shows detectable levels of indicator organisms based on WHO and UNBS drinking water quality guidelines.

### **2.6.1 Total coliforms**

Total coliforms are Gramma-negative, non-spore forming rod-shed bacteria capable of growing in the presence of bile salts, or other surface-active agents with similar growth-inhibiting properties, oxidase-negative, fermenting lactose at 34 – 37°C with the production of acid, gas and aldehyde within 24 – 48 hours (Payment *et al.*, 2003). Due to the fact that some total coliforms of non-feacal origin can be present in natural water, their presence in untreated water can be tolerated. However, when used as an indicator organism for treatment efficiency, their presence should not be detected in treated drinking water. Their detection in treated water provokes an immediate investigation.



Total coliforms provide basic information on the quality of drinking water though not an index of faecal pollution. They are preferred indicator organisms because they are easy to detect and enumerate in a water sample by simple, inexpensive cultural methods that require basic routine bacteriological laboratory facilities with well-trained laboratory technicians. The presence of total coliforms in drinking water sources may be as a result of surface water infiltration or seepage from a septic system (Anwar, Lateef & Siddiqi, 2010).

### **2.6.2 *Escherichia coli***

*Escherichia coli* are taxonomically well defined member of Enterobacteriaceae and are characterized by possession of  $\beta$ -glucuronidase and  $\beta$ -galactosidase. They grow at 44 to 45°C on a complex media, ferments lactose and mannitol with the production of an acid and produces indole from tryptophan. However, some strains can grow at 37°C but not 44 – 45°C and some do not produce a gas. They are abundant in human and animal faeces, very common in sewage, treated effluents and natural waters subject to recent faecal contamination. They are widely preferred index for faecal contamination and are the widely most used indicator of water treatment effectiveness. Their presence in treated water indicates inefficient removal of pathogens.

Verhille (2013) described *Escherichia coli* as the best up to-date microbial indicator available to determine the health risks associated with the consumption of poor quality water. A research study by Odonkor and Ampofo, (2013) reported that two key factors made *Escherichia coli* a popular preferred indicator organism for faecal

pollution in drinking water. Some faecal coliforms are non faecal in origin unlike *Escherichia coli*. The study further reported that *Escherichia coli* provide the best bacterial indication of faecal contamination in drinking water.

WHO drinking water quality guideline for *Escherichia coli* is 0 detectable per 100 ml (Table 2.1). This implies that in order to comply with the guideline, for every 100 ml of drinking water tested, no *Escherichia coli* should be detected in the water sample.

**Table 2.1: Maximum bacteriological limits for treated drinking water**

Counts	Remarks	Action recommended
0 CFU/100 ml	In conformity with WHO guidelines	Water is safe to drink.
1–10 CFU/100 ml	Low risk	Water is of reasonable quality. It may be consumed the way it is.
10–100 CFU/100 ml	Intermediate risk	Water is polluted. Treat if possible but if not, still may be consumed as it is.
101–1000 CFU/100 ml	High risk	Water is highly polluted and must be treated before drinking.
<1000 CFU/100 ml	Very high risk	Water is very much polluted and must be treated thoroughly before it is consumed.

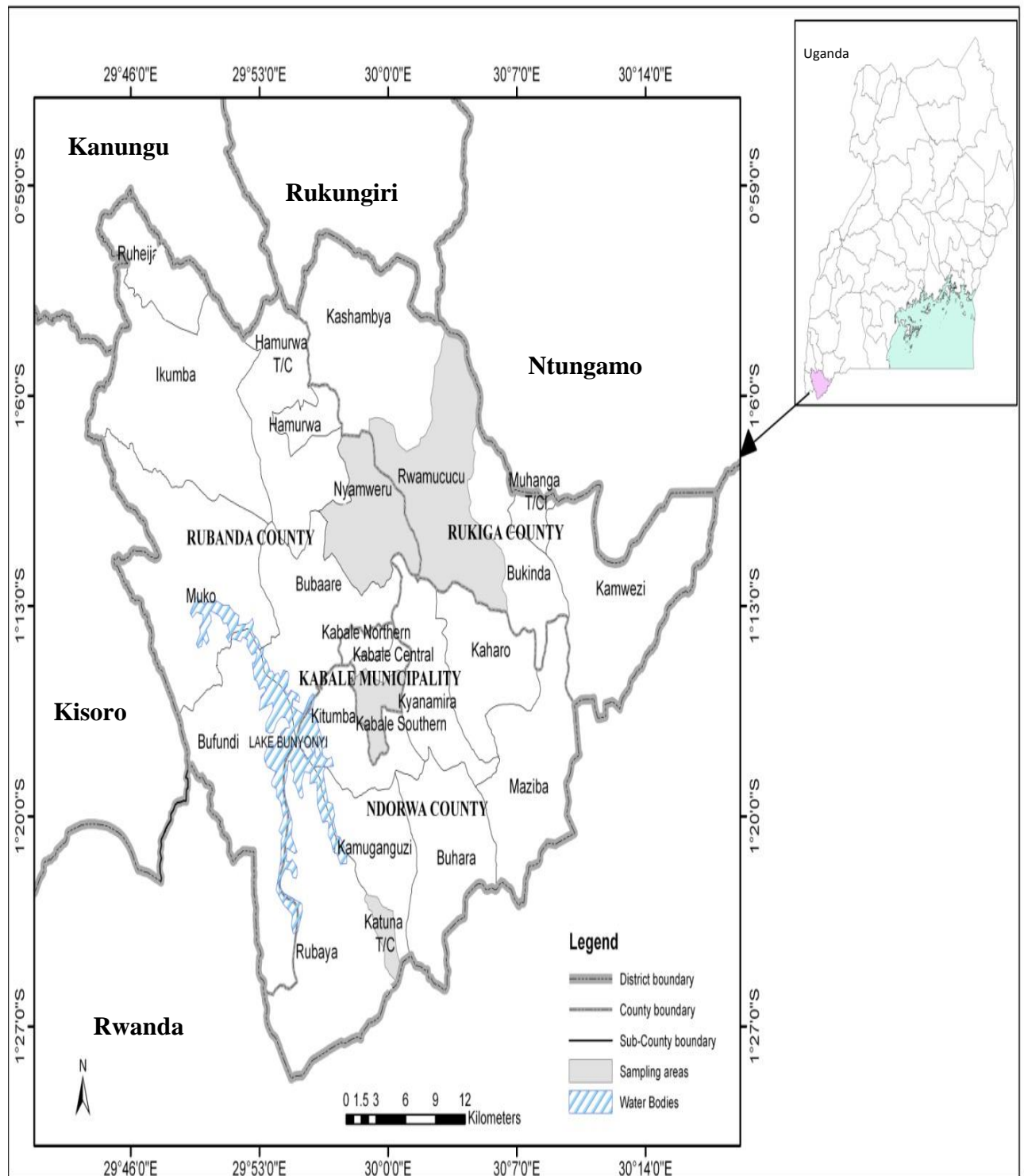
(Source: WHO, 2006)

## **CHAPTER 3: MATERIAL AND METHODS**

### **3.1 Study area**

This study was carried out in Kabale District located in Southwestern Uganda. Geographically, it lies between 29° 45' 0" E and 30° 15' 0"E and latitudes 0° 1' 0" S and 1° 29 0" S (Figure 3.2). It covers a total area of about 1,864 Square kilometers (KDLG, 2012). It borders with the Districts of Kisoro to the West, Rukungiri to the North, Ntungamo to the East and the Republic of Rwanda to the South (KDLG, 2012).

Kabale District has 119,631 households with a population of 534,160 people (UBOS, 2014). Approximately 81% of households have access to safe drinking water sources (DWD, 2010). The main water supply technologies are public stand pipes and protected spring technologies however, in some parts of the district, rain water harvesting is practiced (DWD, 2010). In spite of this relatively high accessibility to safe water sources, the proportion of people with waterborne diseases is relatively high (UBOS, 2012).



**Figure 3.2: Map showing the study area (Kabale District) in southwestern Uganda**

### 3.2 Research design

The study employed analytical and descriptive research designs utilizing mixed methodologies in which both quantitative and qualitative approaches were used in data collection and analysis.

### 3.3 Sampling design

#### 3.3.1 Sample size

The sample size was calculated using simple random sampling formula in order to get a representative number of households to use in the study. The formula developed by Israel (1992) was used to quantify the minimum sample size because it is most appropriate when using simple random sampling design, and yields a good sample size necessary for impact evaluations.

$$n = \frac{N}{1+N(e)^2} \quad 3.1$$

**Where:**

$n$  = required sample size,  $N$  = Population size (119,631) and  $e$  = level of precision (7% equivalent to its standard value 0.07). Substituting in equation 3.1 gives the following sample size;

$$n = \frac{119,631}{1+119,631 (0.07)^2} = 204 \quad 3.2$$

#### 3.3.2 Sampling procedure

The study employed probability sampling with multistage sampling technique (Figure 3.3). At the first level of sampling, all household heads in Kabale District

were targeted during the study. In this case, the sample population was divided into four clusters based on county and municipal political boundaries. At the second level of sampling, each cluster formed was disaggregated into small groups (sub-counties) called strata. Four strata each one from the disaggregated clusters were randomly selected. The up-to-date number of households from each selected stratum (Table 3.2) obtained from respective sub-county chiefs was used to determine the proportionate number of households selected using a simple formula illustrated in equation 3.3. Households from each selected stratum were picked randomly during field study visits.

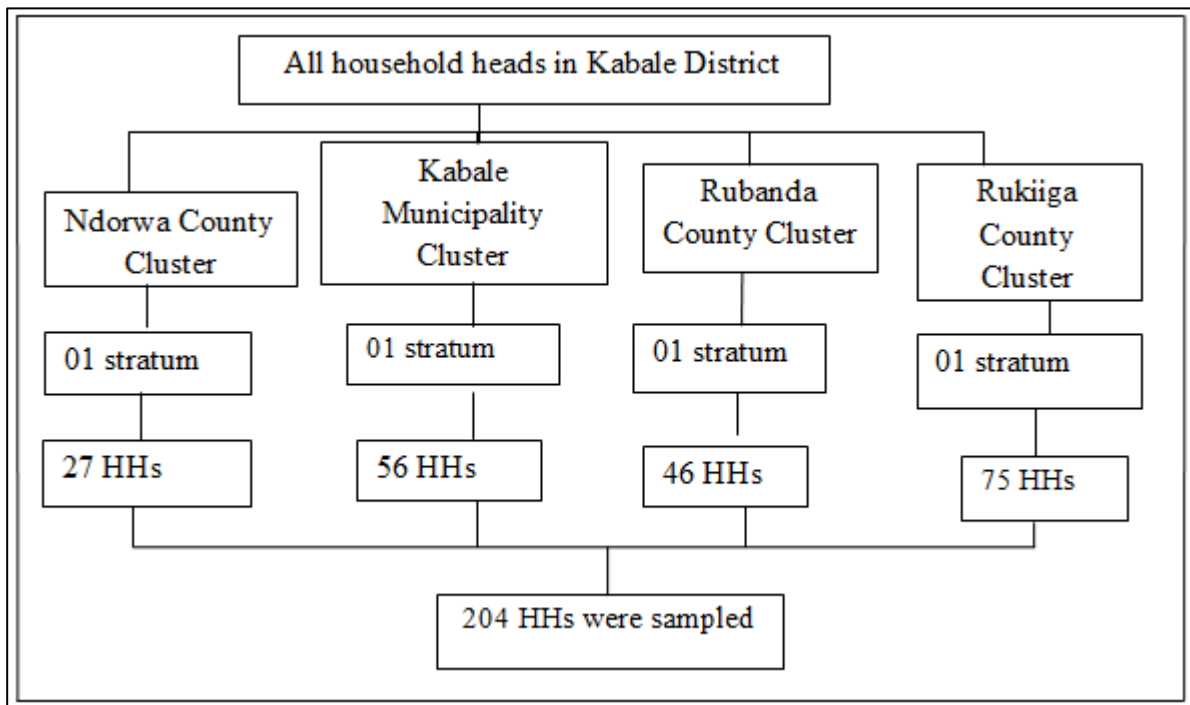
$$Pss = \frac{HHA}{THHA} \times Ss \quad 3.3$$

**Where:**

*PSS* = Proportionate sample size, *HHA* = Number of households per selected sampling area, *THHA* = Total households in selected sampling areas, *SS* = Sample size required.

**Table 3.2: Number of households selected per stratum (sub-counties)**

	Selected strata	Total no. of households per selected stratum	Sample size per selected stratum	Percentage of selected household samples
Valid	Kabale Municipality South	4,478	56	27.3
	Katuna	2,157	27	13.2
	Nyamweru	3,685	46	22.5
	Rwamucucu	5,959	75	36.8
	<b>Total</b>	<b>16279</b>	<b>204</b>	<b>100</b>



**Figure 3.3: Multistage sampling design used in this study**

### 3.4 Data collection methods

#### 3.4.1 Field study survey

The purpose of the field survey was to establish the socio-economic and demographic characteristics of households, identify sources of drinking water, HWTS and to establish the reasons for use of different HWT. Semi-structured questionnaires (Appendix I) were used to collect socio-economic and demographic data, data on drinking water sources, HWTS and the reasons for use of different HWT. The questionnaire was divided into three sections. Section A assessed the socio-economic and demographic characteristics of respondents, section B assessed sources of drinking water and section C assessed HWTS.

### **3.4.2 Water sampling**

For each household visited, both treated and untreated water samples (if the household head reports them available) were collected aseptically in sterilized 500 ml bottles during unannounced visits. For purposes of quality, field samples were collected in duplicates. The bottle corks were shielded with aluminum foil in order to avoid any form of hand contamination and adhere to aseptic techniques. The researcher assigned identification numbers to each water sample and recorded the time of sampling, type of the sample (whether treated or untreated) and the technology used to treat it. The number of days the treated water had stayed up to sampling time was recorded. All water samples were stored at 4°C before analysis.

Experiment test water samples were collected from four unprotected water springs namely; Sapato, Hamwaro, Mukakyenkye and Kirigime water springs reported with high bacterial contaminants during our field study visits. Thereafter, each sample unit was treated by all the five treatment technologies under study that were identified during the field study survey. These include; biosand filters, aqua safe tablets, boiling method, WaterGuard tablets and let it stand and settle method. All the water samples were tested for both total coliforms and *Escherichia coli* before and after treatment in accordance with standard methods for the examination of water and wastewater (APHA, 1981).

### **3.5 Pre-testing of the research instruments**

Research instruments for this study were tested in the northern Kabale municipality prior to data collection. Questionnaires were tested to check whether they generate



the intended data. Errors identified were noted and corrected before the actual field study.

### **3.6 Data management**

Filled questionnaires were checked for completeness at the end of each data collection day within the field to identify any missing data before leaving the field. Water samples were diligently labeled in the field and transported at room temperature to the laboratory for safe storage and analysis. Water samples were stored at room temperature for about 2 to 3 hours before they were analyzed.

### **3.7 Quality assurance and quality control**

When assessing effectiveness of HWT for microbial removal, quality control and quality assurance are absolutely important. Standard methods and procedures were employed with all relevant parameters such as detection limits, repeatability and storage conditions of samples. Upon collection, samples were immediately placed on ice in coolers and then transported to the laboratory at 4°C. Upon arrival at the laboratory, samples were refrigerated at 4°C, and analyzed within six hours of collection. Previous studies indicate that such a holding time has little effect on measured total coliforms and *Escherichia coli* concentrations at temperatures less than 10°C, although analysis should always be conducted as rapidly as possible (Pope *et al.*, 2003). All the bacterial analyses were carried out at NWSC-Kabale area water laboratory.

### 3.8 Data analysis

#### 3.8.1 Laboratory analysis

Membrane filtration method was used in analysis of water samples in accordance with standard methods for the examination of water and wastewater. 100 ml of water were aseptically drawn from each unit of the samples and filtered through a 0.45 µm millipore filter membrane. The membrane was aseptically removed from the filtration unit by using sterile forceps and placed on the medium in the petri-dish in a rolling motion to avoid entrapment of air. Total coliforms and *Escherichia coli* counts were determined by incubating the membrane filter on Hichrome media at 37°C and 44°C for 24 hours, respectively. In order to ascertain the number of total coliforms and *Escherichia coli* contained in each incubated sample, colony forming units (CFU) developed on the membrane filter after incubation were counted.

Effectiveness of HWT was determined by testing the bacteriological quality household water samples (before and after treatment) and extended laboratory testing for bacterial reduction in source water by HWT identified during unannounced field study visits. Reduction of total coliforms and *Escherichia coli* indicator organisms in water samples before and after treatment was key performance outcome measured. Enumeration of total coliforms and *Escherichia coli* before and after treatment was done following standard methods for the examination of water and wastewater (APHA, 1981, 1995; Rice, Bridgewater, & APHA, 2012; WE Federation, 2005). Log<sub>10</sub> bacterial reductions were calculated using the equation below and were

converted to percentage reduction. The formula for calculating bacteria removal efficiency is shown in equations 3.4 – 3.5 (Martin, 2010).

$$LR = \log_{10}(B.C_b) - \log_{10}(B.C_a) \quad 3.3$$

$$PR = \frac{B.C_b - B.C_a}{B.C_b} \times 100\% \quad 3.4$$

**Where:**

$LR$  = log reduction,  $PR$  = percentage reduction,  $B.C_b$  = bacteria count before treatment,  $B.C_a$  = bacteria count after treatment.

### 3.8.2 Statistical analysis of data

Descriptive statistics were used to analyse socio-economic, demographic and laboratory data. Pie charts, bar graphs, and line graphs, were used to explain the bacterial characteristics of water samples before and after treatment in relation to WHO standards for drinking water quality, establish the different sources of water, HWTS, and the reasons for use of different household water treatment technologies in Kabale District, southwestern Uganda.

Chi square test was used to test the association between socio-economic and demographic factors and the type of water treatment technologies used at household level. A Paired samples T-test was used to compare mean difference between bacteria counts in household drinking water samples before and after treatment. One way ANOVA was used to compare mean differences between bacteria reductions by different HWT in experiment test water samples. All tests were compared at 95%

confidence level. If the probability (p) value was less than 0.05, the test was significant but p-value greater than 0.05 showed no significant difference between the variables compared. The statistical tests were performed in SPSS version 17.0.

### **3.9 Ethical considerations**

Before the actual study, the researcher requested for permission from respective sub-county administrators two weeks prior to the actual field study. Informed consent from the respondents was obtained during the field study and participation was voluntarily. The identity and information given by the respondents was confidential. Only questionnaire numbers helped to link respondents' answers to water testing results in the laboratory.

## **CHAPTER 4: RESULTS AND DISCUSSION**

### **4.1 Introduction**

This chapter presents the results and cover discussion of findings from the field survey and laboratory analyses conducted in Kabale District southwestern Uganda. Results on sources of drinking water, household water treatment and storage options used and the reasons for use of different household water treatment technologies are discussed in this chapter. Bacteriological quality of treated drinking water is evaluated to determine the effectiveness of water treatment technologies at household level.

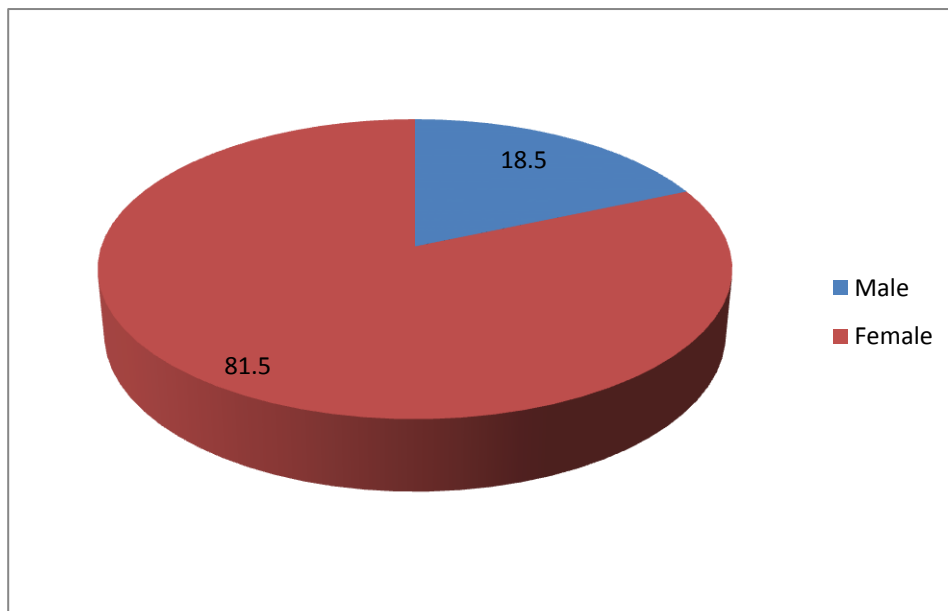
### **4.2 Socio-economic and demographic characteristics of respondents**

Socio-economic and demographic characteristics evaluated in this study include; gender, age, occupation, level of income, marital status, level of education and household size. These characteristics were selected because they influence the use of different household water treatment technologies.

#### **4.2.1 Gender of respondents**

Out of 205 household heads that were randomly sampled, 81.5 % were female respondents and 18.5% were male respondents (Figure 4.4). Gathering household information from both sexes on the same issues provided gender perspectives and helped in assessing the reliability of the responses from the field study survey. Women in rural areas were more involved in regular farm activities than men thus, with limited time to undertake household activities such as household water

treatment. Schmidt and Cairncross (2009) reported that household water treatment contributes less to economic and educational activities of women since it does not affect water supply. Instead, household water treatment increase work load of household members, especially women, although probably not to a very substantial extent.

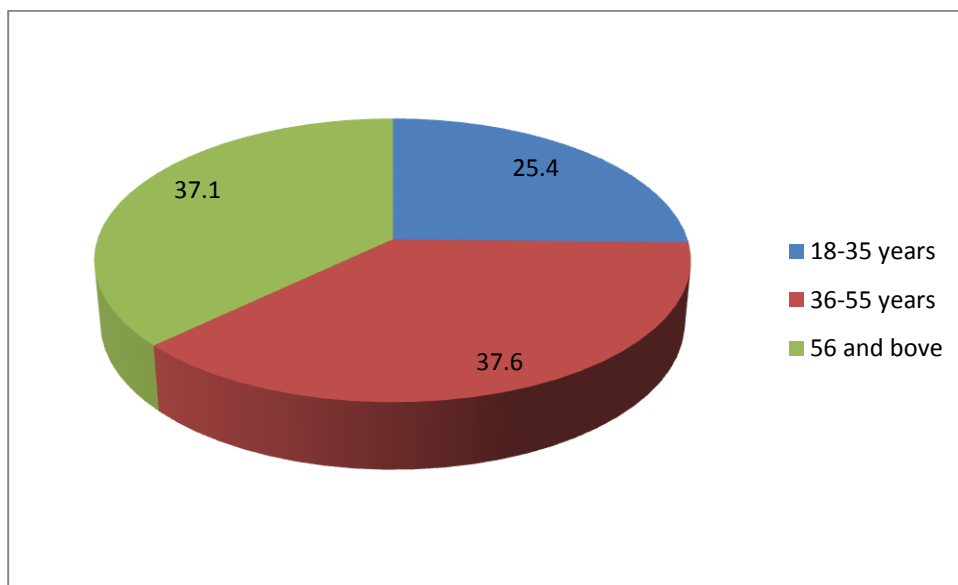


**Figure 4.4: Pie chart showing percentage of respondents**

#### **4.2.2 Age of respondents**

As shown in figure 4.5, respondents were grouped into three categories based on their age. Majority of respondents (74.7%) were above 36 years of age. This was because the study basically targeted household heads. Only 25.4% of respondents were in the youth age bracket (18–35). Elderly people tend not to labour so much in implementing household water treatment which is at times rigorous, labour intensive and sometimes have cost implications. They tend to be conservative, sticking to their

traditional and inappropriate methods of household water treatment. Most young people are passionate in combatting diseases so as to live longer. They know about diseases that spread as a result of drinking contaminated water and are more interested in household water treatment. The study revealed that all the respondents between 18–35 years of age reported they were practicing household water treatment. Wright and Gundry (2009) reported that younger household heads are more open to newer HWT such as chlorination than older household heads who tend to rely more on traditional HWT.

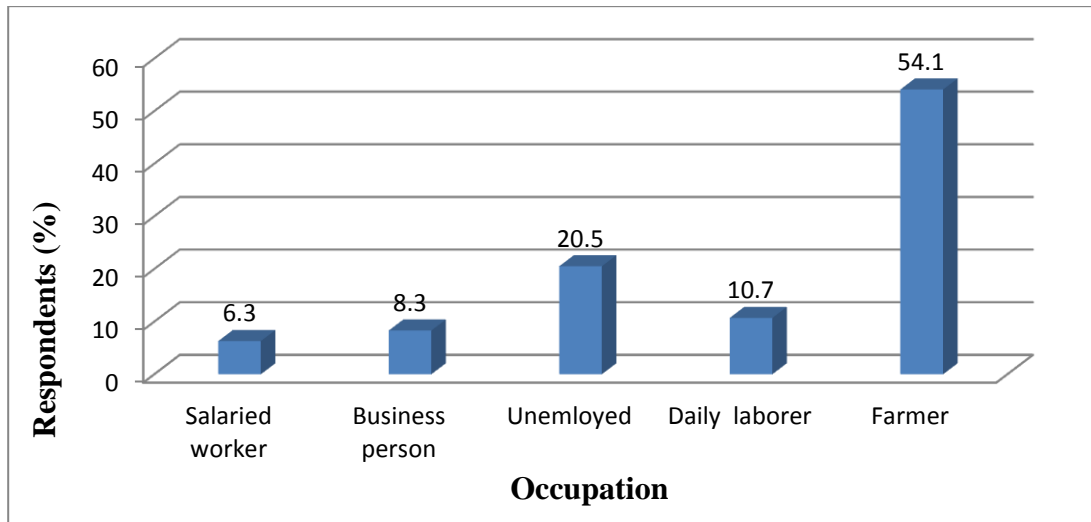


**Figure 4.5: Pie chart showing age of respondents**

#### **4.2.3 Occupation of respondents**

As shown in figure 4.6, majority of respondents were farmers (54.1%) followed by daily labourers (10.7%), business people (8.3%) and salaried workers (6.3%). It was further noted that 20% did not identify their sources of income. Majority

respondents being farmers clearly indicates that agriculture is the economic base of the people in the study area. Other identified sources of income are meant to supplement agricultural produce.



**Figure 4.6: Bar graph showing occupation of respondents**

#### **4.2.4 Level of income**

Table 4.3, shows household income per month, classified into four groups. It was found out that monthly income for 73.7% households ranged from 10,000 to 200,000 UGX, for 7.8% households ranged from 400,000 to 600,000 UGX and for 1% households was above 600,000 UGX. The study revealed that 10.7% of households were not earning anything per month. Some household water treatment technologies may be moderately costly and only affordable by rich household heads. In poorer communities, for example, a substantial proportion of households were boiling their drinking water because it is cheap compared to other water treatment technologies.

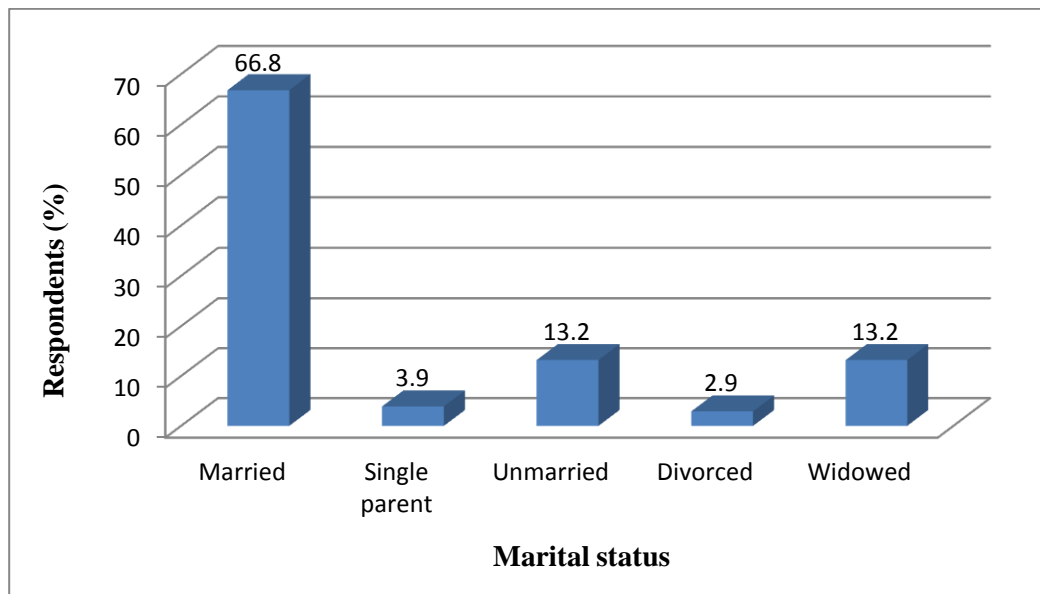


**Table 4.3: Income distribution of households per month**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	10,000 – 200,000 UGX	151	73.7	73.7	73.7
	200,000 – 400,000 UGX	14	6.8	6.8	80.5
	400,000 – 600,000 UGX	16	7.8	7.8	88.3
	600,000 UGX and above	2	1.0	1.0	89.3
	Nothing	22	10.7	10.7	100.0
	Total	205	100.0	100.0	

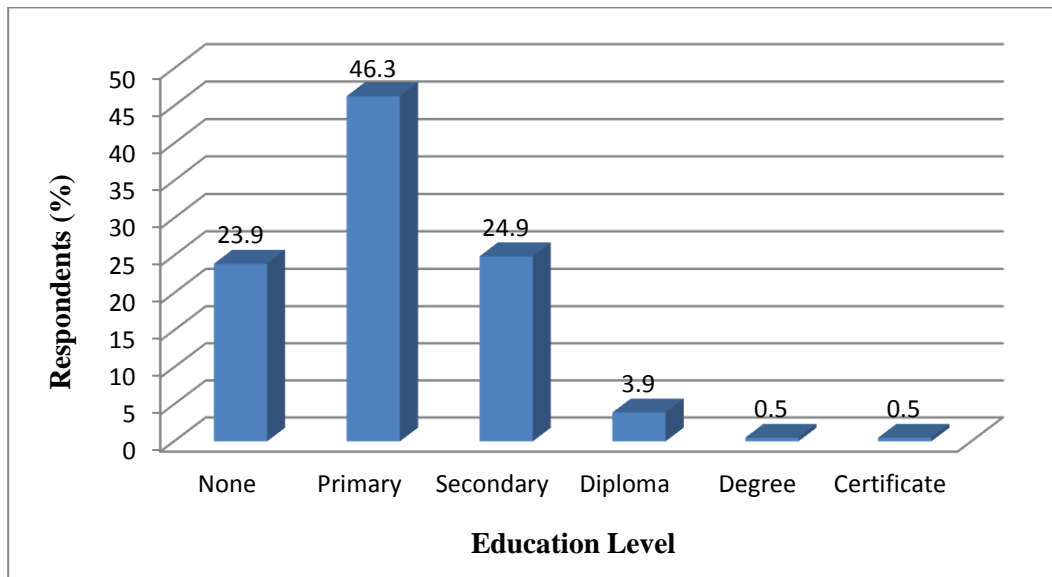
#### 4.2.5 Marital status of respondents

As shown in figure 4.7, 66.8% respondents were married, 13.2% were unmarried, 2.9% were divorced and 3.9% were single parents. It was revealed that 13.2% had lost either of their spouses.

**Figure 4.7: Bar graph showing marital status of respondents**

#### **4.2.6 Education level of respondents**

The study findings revealed that majority of respondents had attained education to a certain level. The study revealed that 46.3% had attained primary level education, 24.9% had attained secondary level education and 3.9% had attained education equivalent to a diploma. Additionally, 1% had attained education equivalent to advanced certificate and university degree (Figure 48). Additionally, 23.9% of respondents did not have any formal education (Table 4.12). Good practice of household water treatment requires knowledge of effective household water treatment. Respondents with some formal education had some knowledge on household water treatment and the possible outcomes that may emanate from drinking contaminated water. For those who didn't have any formal education and had never had any training admitted to have ever heard about household water treatment but were adamant to change their traditional ways of water purification. Wright and Gundry (2009) found out that people with more years of formal education were aware of the dangers of unsafe drinking water and were more likely to treat their drinking water. A post implementation evaluation of chlorine use at household level in Zambia after a promotion campaign found that chlorine use was significantly greater among those with post-secondary education level (Olembo *et al.*, 2004).



**Figure 4.8: Bar graph showing education level of respondents**

### 4.3 Sources of household drinking water

The study findings revealed that 61.5% of respondents get their drinking water from water springs, 19% from public taps, 4.4% from private taps, 8.8% from neighbors' taps, 1.5% from shallow wells and 0.5% from boreholes (Table 4.4).

**Table 4.4: Sources of household drinking water**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Private tap	9	4.4	4.4	4.4
	Shallow well	3	1.5	1.5	5.9
	Public tap	39	19.0	19.0	24.9
	Borehole	1	.5	.5	25.4
	Water spring	126	61.5	61.5	86.8
	More than one source	9	4.4	4.4	91.2
	Piped water from the neighbor	18	8.8	8.8	100.0
	Total	205	100.0	100.0	

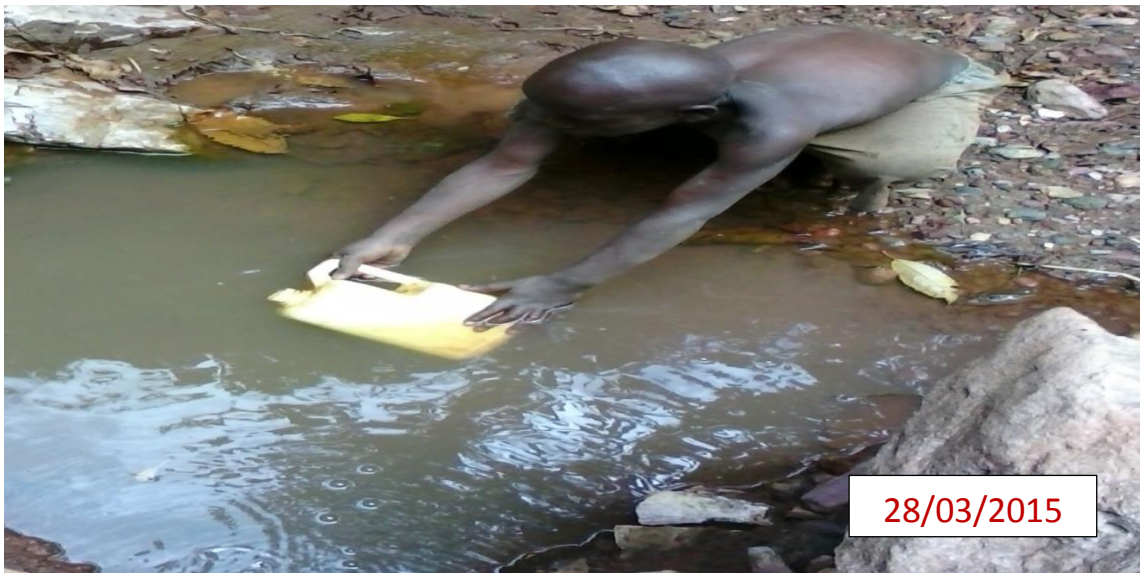
The taps and boreholes were both privately and publicly owned. Water springs were publically owned. Shallow wells were constructed by local people faced with limited access to safe drinking water. Most toilets in the study area were constructed in less than 20 meters away from water springs (Plate 4.1). This explains why majority of water samples from springs were associated with high total coliforms and *Escherichia coli* concentrations. In addition, crops were seen grown in less than 10 meters away from water sources.

Constructing toilets in close proximity to drinking water source puts it at risk of faecal contamination. In related study by Sivaraja and Nagarajan (2014) found out that River Cauvery in India was loaded with coliform bacteria attributable to raw sewage. Abdulkadir *et al.* (2015) reported high concentration microbes in drinking water sources located in close proximity to pit latrines. Establishing crop farms in close proximity to drinking water sources puts it at risk of chemical contamination especially when fertilizers, organic manure and pesticides applied on crop farms end up in drinking water sources by runoff water after heavy rains. Nassar (2015) reported high nitrate concentration in the majority of wells with typical values of 100 – 300 ppm, and exceeding 600 ppm in some other areas of the Gaza Strip.



**Plate 4.1: Water springs (Source: Field survey)**

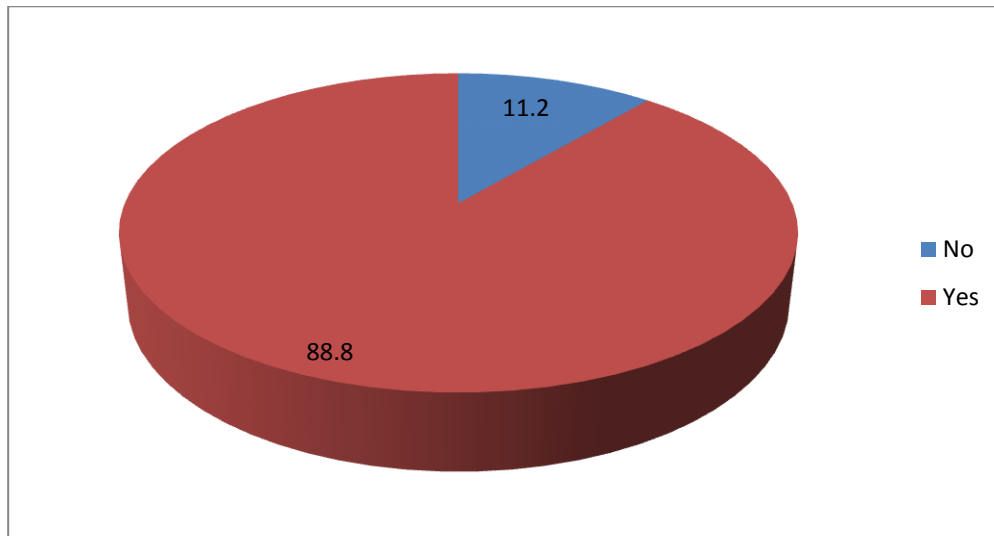
Shallow wells were unprotected and their mode of formation and location exposed them to high contamination. One would first step in water in order to get well positioned to collect it. High turbidity and sediment levels characterized wells observed (Plate 4.2). Runoff from crop farms in the shallow wells' upstream was responsible for high turbidity and sediment levels. In such situation, chemical compounds such as nitrogen and phosphorus from fertilizers applied on crop farms, metals and toxins from farm tools may end up in drinking water sources as a result of runoff water after rains.



**Plate 4.2: Unprotected shallow wells (Source: Field survey)**

Regarding water availability at the source, 182 (88.8%) respondents reported that water was always available whereas 23 (11.2%) reported that it was not always available for use (Figure 4.9). In rural Kabale District, irregular water supply is linked to two major reasons; when cleaning water supply tanks, water supply may be limited for a short time. When there is a technical problem in water distribution system, people do not get water at their taps in some places. In urban Kabale District, especially, in areas supplied by national water and sewerage corporation (NWSC), irregular water supply is linked to three major reasons; Power outages: When power goes off for some hours or days, water pressure goes down and water flow in the supply pipes suddenly stops. Mechanical problems such as pipe busting lowers water pressure and thus water fail to reach to some water supply points. Cleaning water supply tanks sometimes also affects water supply especially when

water demand is much higher and reserve tanks cannot handle the overwhelming water demand.



**Figure 4.9: Pie chart showing percentage response of respondents on availability of water from source**

Regarding frequency of collecting water from the source, the present results show that 20.5%, 42%, and 24.6% were collecting drinking water from the source once in a day, two times in a day, three times in a day respectively. Additionally, 6.8%, 2.9% and 3.4% were collecting drinking water from the source, four times in a day, five times in a day and more than six times in a day respectively (Table 4.5). The study revealed that respondents whose drinking water sources were water springs were collecting drinking water from the source more frequently than those whose sources were private or public taps. This means that type of drinking water source influences the number of times water users can collect water from source per day.

**Table 4.5: Frequency of drinking water collection from the source**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Once a day	42	20.5	20.5	20.5
	Twice a day	86	42.0	42.0	62.4
	Thrice a day	50	24.4	24.4	86.8
	4 times a day	14	6.8	6.8	93.7
	5 times a day	6	2.9	2.9	96.6
	More than 6 times a day	7	3.4	3.4	100.0
	Total	205	100.0	100.0	

#### **4.4 Household water treatment and storage options**

##### **4.4.1 Household water treatment**

The current study reveals that 75.6% of households were using any one of the following HWT: boiling, biosand filtration, let it stand and settle method, application of WaterGuard tablets and application of aqua safe tablets. Additionally, 24.4% were not using any HWT to purify their drinking water. Research has shown household water treatment as the most effective way of preventing waterborne diseases such as diarrhea, typhoid, and cholera among others. Schmidt and Cairncross (2009) found out that apart from potential to reduce diarrhea, household water treatment improves aesthetic appeal of drinking water and reduces indoor air pollution.

Of all HWT reported, boiling was noted the most common method both in rural and urban areas, and was used by both educated and uneducated people in the study area. Let it stand and settle is common in rural areas, practiced by people with low education level and the elderly. Biosand filtration method is latest of all HWT however; its uptake has considerably been low since its inception.



The study findings revealed that, out of 155 respondents who reported treating water with any one technology, 67.3% reported they were using boiling method, 1% reported they were using aqua safe tablets, 4.4% reported they were using let it stand and settle method, 2.4% reported they were using biosand filtration method and 1.5% reported they were using WaterGuard tablets (Table 4.6). The results of this study concur with research findings by Kakulu (2012) that reported boiling method as the most popular household water treatment method with (43.6%).

The present study findings do not support Wright and Gundry (2009) who found out that water filtration and let it stand and settle methods were in widespread use. In addition, the results of this study do not support Sreenivasan *et al.* (2015) who found out that majority respondents (75%) were using WaterGuard as their most preferred water treatment method.

**Table 4.6: Household water treatment technologies**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Boiling	138	67.3	67.3	67.3
	Aqua safe tablets	2	1.0	1.0	68.3
	Let it stand and settle	9	4.4	4.4	72.7
	Biosand filtration	5	2.4	2.4	75.1
	WaterGuard tablets	3	1.5	1.5	76.6
	Don't use any HWT	50	24.4	24.4	100.0
	Total	205	100.0	100.0	

Table 4.7 shows the reasons why respondents were using different HWT. It was found that the majority who were using boiling because it was easy to use (23.2%), cheap to use (20.6%), and makes water safer to drink (7.7%). The perception that boiling is easy to use has been a result of sensitization from the ministry of health through VHTs. The study further revealed that respondents were using boiling because it had positive health impacts (9%). This indicates that awareness of the health benefits of household water treatment by VHTs has been really understood. Other respondents revealed they were using boiling because they did not know about others (18%). The study results support Sodha *et al.* (2011), who found out that 83% respondents were using boiling because it was practical, 73% said it was easy to use, 90% believed it was cheap and only 4% felt that boiling was difficult. The study findings also support Kakulu (2012) who found out that majority of respondents were using boiling method because the method was cheap to use and did not know about other treatment options. Respondents were using let it stand and settle method because it was easy to use (66.7%), cheap to use (33.3%).

Some respondents reported they were using biosand filtration because it was easy to use (40%), cheap to use (40%), and required less time to produce ready to drink water (20%) as indicated in table 4.7. In addition, 20% of respondents reported they were using biosand filtration method because it was able to produce much volume of drinking water in a short time.

It was found out that respondents were using WaterGuard and aqua safe tablets because they believed the tablets were easy to use, cheap to use and required less

time to produce drinking water (Table 4.7). Stockman *et al.* (2007) found out that 68% were using WaterGuard because they believed it makes water safe, 21% believed it prevents diarrhea and 10% didn't justify why they were using WaterGuard. Freeman *et al.* (2009) found out that WaterGuard which was commercially launched less than one year before the evaluation had a lower level of use because it was perceived to be more expensive water treatment product at US\$ 0.02 per 100 litres than other water treatment products such as Klorin and PUR. In a related study, Jain *et al.* (2010) reported that respondents were using NaDCC tablets because they believed the tablets would improve human health (63%), prevent diseases (45%), make drinking water safer (43%), be easy to use (21%) and improve the taste of their drinking water (16%). It was further noted that 2% complained of bad smell and 1% bad taste from drinking water treated by NaDCC tablets.

**Table 4.7: Reasons for use of different household water treatment technologies**

Treatment option	Cheap to use	Easy to use	Makes water more safe	Produce enough volume of drinking water	Require less time	Has health benefits	Don't know other methods (%)	Total
Boiling	32 (20.6%)	36 (23.2%)	13 (7.7%)	11 (7.1%)	4 (2.6%)	14 (9%)	28 (18%)	138 (67.3%)
Biosand filtration	2 (40%)	2 (40%)	0	1(20%)	0	0	0	5(2.4%)
Aqua safe tablets	0	1(50%)	0	0	0	1(50%)	0	2 (1%)
Let it stand and settle	3 (33.3%)	6 (66.6%)	0	0	0	0	0	9 (4.4%)
WaterGuard	1 (44.4%)	2 (66.7%)	0	0	0	0	0	3 (1.5%)

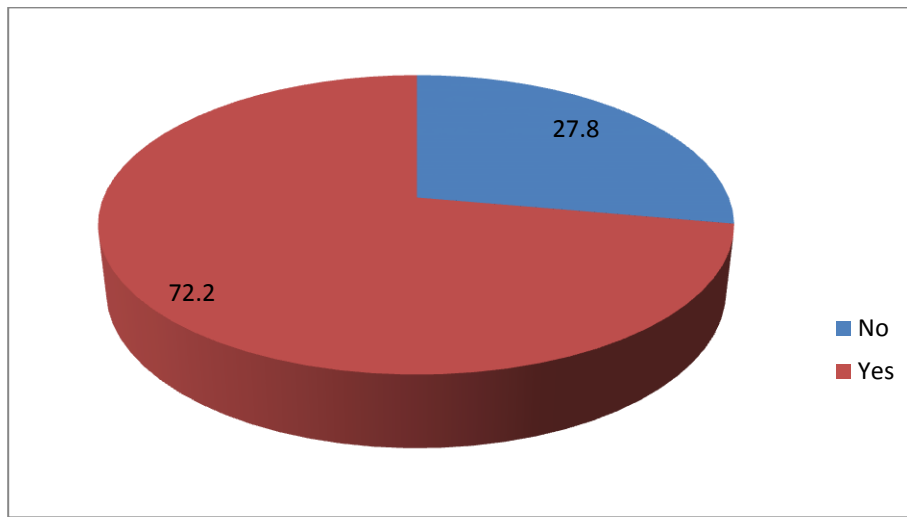
As shown in table 4.8, research findings established from respondents revealed that majority households were not practicing household water treatment because; treated water had bad taste and smell (6.3%), they were used to drinking untreated water (5.9%) and others believed that their drinking water sources were safe (7.8%). The study findings concurs with Kakulu (2012), who found out that respondents were not treating their drinking water because they believed that it is safer from the source, did not have knowledge on existing household water treatment methods and cost of household water treatment was high. These results imply that people are not well sensitized about the importance of household water treatment and the dangers related to consumption of untreated water. In a related research study by Sodha *et al.* (2011) reported that among 28 respondents who did not treat their drinking water, 36% said consumption of untreated drinking water was their habit while 21% believed their source water was already safe.

**Table 4.8: Reasons for not treating household drinking water**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	It is expensive	4	2.0	2.0	2.0
	Bad taste and smell of treated water	13	6.3	6.4	8.3
	I believe water is safe from the source	16	7.8	7.8	16.2
	We are used to drinking untreated water	12	5.9	5.9	22.1
	Time consuming	2	1	1	23.1
	Not applicable	155	75.6	76.0	98.7
	Others	2	1.0	1.0	99.7
	Very old and not have the energy to do treat water	1	.5	.5	100.0
	Total	205	100.0	100.0	

#### 4.4.2 Household water storage practice

As shown in figure 4.11, 72.2% respondents reported they were storing drinking water in any water storage container, whereas 27.8% reported they were not storing drinking water. Of those who reported they were storing drinking water, only 27.8% of respondents had treated drinking water whereas 54.8% didn't have it during field study visits. Household water storage options that were reported include; 5-litre jerricans (33.7%), plastic buckets (13.7%), 20-litre jerricans (13.2%), jugs (7.8%) and 2.9% were using plastic bottles (Table 4.9). Other household water storage options such as clay pots (0.5%), kettles (1%), beakers (0.5%) and flasks (0.5%) were reported as shown in Table 4.9. 5-liter jerricans were preferred because they are generally cheap light and durable. Plastic buckets were preferred because are they easy to clean; 20-liter jerricans were preferred because they were storing much drinking water for quite a number of days and plastic bottles were preferred because are cheap and in some cases free of charge. The current study supports Harris *et al.* (2009), who reported that household water storage containers such as clay pots (62%), jerricans (21%), barrels (7%), buckets (5%), jugs (3%), and bottles (1%) were used by mothers before KiBS (Kisumu Breastfeeding Study) clay pots were introduced.



**Figure 4.10: Pie chart showing percentage response of respondents on household drinking water storage**

**Table 4.9: Household drinking water storage options**

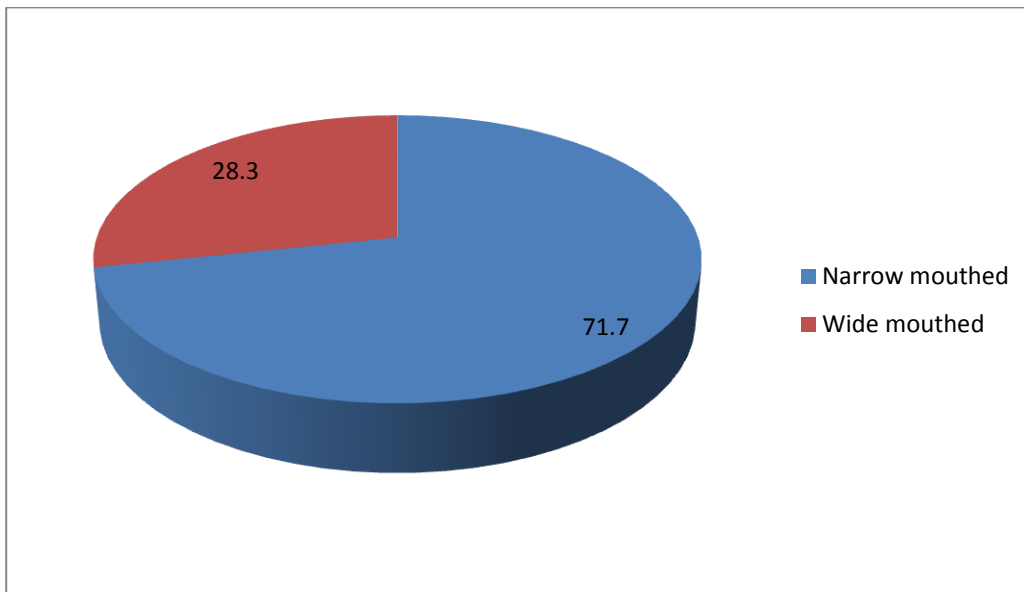
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Clay pot	1	.5	.5	.5
	Plastic bucket	28	13.7	13.7	14.1
	Plastic bottle	6	2.9	2.9	17.1
	Steel bucket	1	.5	.5	17.6
	5 Litre Jerrican	69	33.7	33.7	51.2
	Not applicable	53	25.9	25.9	77.1
	Jug	16	7.8	7.8	84.9
	Flask	1	.5	.5	85.4
	Jerrican	27	13.2	13.2	98.5
	Beaker	1	.5	.5	99.0
	Kettle	2	1.0	1.0	100.0
	Total	205	100.0	100.0	

Of 57 (27.8%) respondents who reported they were not storing drinking water, majority reported they were not doing so because; the odor of stored water was bad (9.8%), storage containers could not last for long (2.4%), and the cost of storage vessels were high (7.3%) as shown in table 4.10.

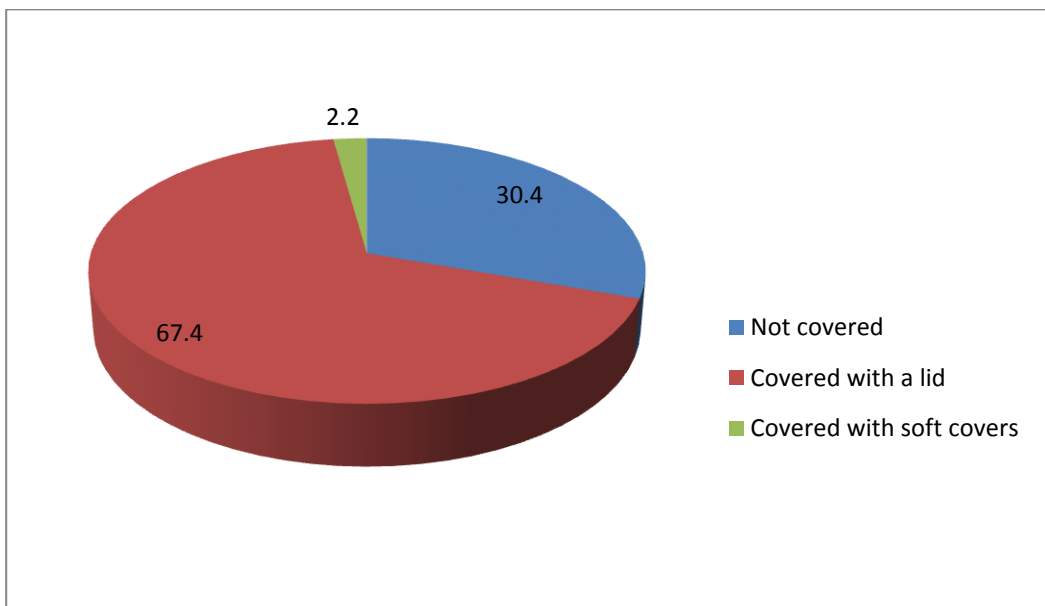
**Table 4.10: Reasons for not storing drinking water**

		Frequenc y	Percent	Valid Percent	Cumulative Percent
Valid	The odor of stored water is bad	20	9.8	9.8	9.8
	Storage containers usually don't long last	5	2.4	2.4	12.2
	Can't afford the cost of water storage vessels	15	7.3	7.3	19.5
	Not applicable	154	75.1	75.1	94.6
	Don't have a storage container	4	2	2	96.6
	Rarely drink water	1	.5	.5	97.1
	Don't have water guard to use	1	.5	.5	97.6
	Don't have time	4	2.0	2.0	99.6
	Laziness	1	.5	.5	100.0
	Total	205	100.0	100.0	

Regarding characteristics of household water storage containers, 71.7% were narrow-mouthed, 28.3% wide-mouthed (Figure 4.11). Additionally, 67.4% household water storage containers covered with a lid, 2.2 % were covered with soft covers and 30.4% were not covered with anything (Figure 4.12). Storing drinking water in wide-mouthed containers is not recommended for storing drinking water because a wide-mouth opening greatly increases the risk of contaminating stored drinking water (Banda *et al.*, 2007; Eshcol *et al.*, 2009). The fact that people cannot dip their hands into drinking water stored in narrow mouthed water storage containers lowers the risk of fecal contamination. On the other hand, WHO (2013) reported that wide-necked containers such as buckets fitted with tight fitting lids are the best household water storage containers since they are easy to clean.



**Figure 4.11: Pie chart showing percentage of narrow and wide mouthed water storage containers**



**Figure 4.12: Pie chart showing percentage of the observed characteristics of water storage containers**



Regarding the style of drawing drinking water from the storage container, 60.5% reported that they were pouring it into drinking cup, 11.7% reported that they were dipping the cup into water in the storage container and 1.5% reported that they were dipping with a ladle into stored drinking water and 1% reported that they were drinking directly from the storage container (Table 4.11). Drawing drinking water from storage container by dipping the drinking cup increases chances of contaminating stored drinking water. Pouring drinking water into the cup is advisable practice if the household cannot afford improved household safe water storage options with taps. Collecting drinking water by dipping a cup into stored water is unsafe household practice and increases chances of water contamination by hand or fingers. Accessing drinking water by dipping a cup into the top of the container increases the chance of stored water contamination by hands (Brick *et al.*, 2004).

**Table 4.11: Style of drawing drinking water from storage container**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Dip with a cup	24	11.7	11.7	11.7
	Dip with a Ladle	3	1.5	1.5	13.2
	Dip with bowl, cup or glass without a handle	1	.5	.5	13.7
	Pour into drinking cup	124	60.5	60.5	74.1
	Not applicable	52	25.4	25.4	99.5
	Drink directly from the storage container	1	.5	.5	100.0
	Total	205	100.0	100.0	

#### 4.5 Testing hypothesis I

The Chi square test was used to test null hypothesis of source of drinking water does not influence the type of water treatment technology used at household level. As shown in tables 4.12 and 4.13, the analysis showed no significant relationship between drinking waters and the type of household water treatment technologies ( $\chi^2(30) = 24.469, P = 0.750$ ). These results indicate that there is no close association between the sources of drinking water and household water treatment technologies used at household level.

**Table 4.12: Cross tabulation showing the relationship between sources of water and household water treatment technologies.**

Count								
		Method of water treatment						Total
		Boil	Add Aqua safe tablets	Let it stand and settle	Biosand Filtration	Water guard	Do not use any HWT	
Sources of water	Private Tap	8	0	0	0	0	1	9
	Shallow well	3	0	0	0	0	0	3
	Public Tap	27	0	0	0	1	11	39
	Borehole	0	0	0	0	0	1	1
	Water spring	84	2	5	5	1	29	126
	More than one source	5	0	2	0	0	2	9
	Piped water from the neighbor	11	0	2	0	1	4	18
Total		138	2	9	5	3	48	205

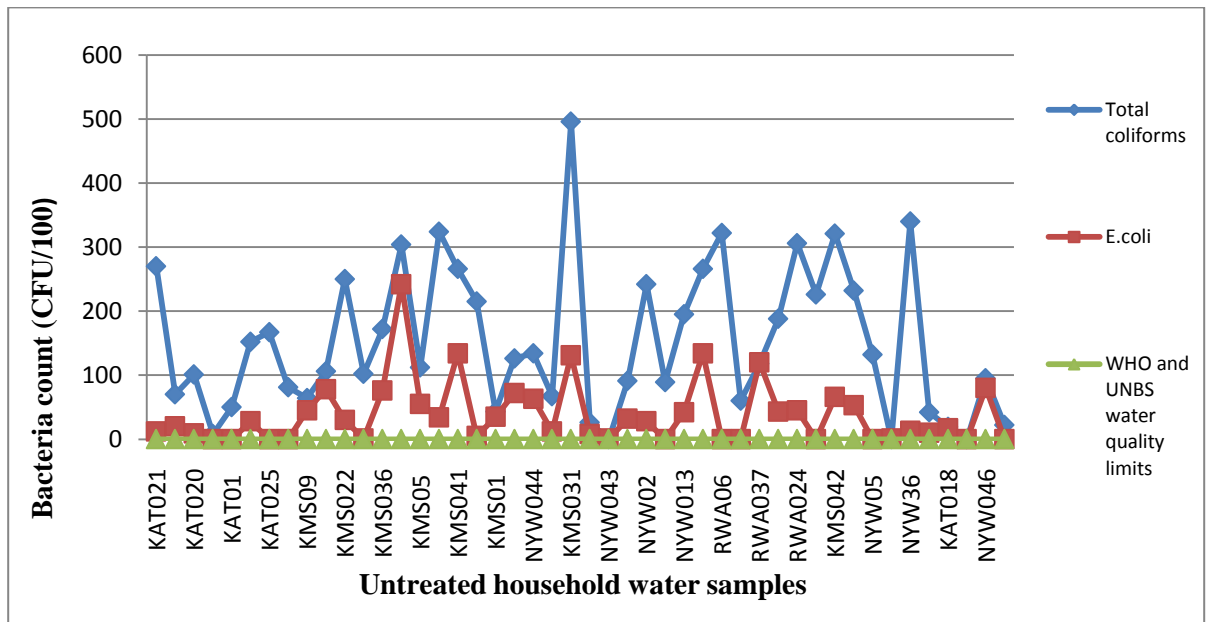
**Table 4.13: Chi-Square tests results showing the relationship between drinking water sources and the type of household water treatment technologies**

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	24.469 <sup>a</sup>	30	0.750
Likelihood Ratio	25.112	30	0.720
Linear-by-Linear Association	1.018	1	0.313
N of Valid Cases	205		
a. 34 cells (81.0%) have expected count less than 5. The minimum expected count is .01.			

#### **4.6 Bacteriological characteristics household drinking water samples before and after treatment**

##### **4.6.1 Bacterial concentration before treatment**

Figure 4.13 shows the concentration of total coliforms and *Escherichia coli* in untreated household test water samples. Total coliforms ranged from 0 to 496 CFU/100 ml whereas *Escherichia coli* ranged from 0 to 242 CFU/100 ml.



**Figure 4.13: Concentration of bacteria in untreated household tested water samples**

Table 4.14 illustrates the frequencies and percentages of household untreated test water samples falling under different risk categories; 0 CFU/100 ml (no risk/ in compliance), 1 to 10 CFU/100 ml (low risk), 11 to 100 (medium risk), 101 to 1000 (high risk) and <1000 CFU/100 ml (Very high risk). It was revealed that only 6.5% of untreated test water samples were free of total coliforms (0 CFU/100 ml), 4.3% fell within the low risk category (1 to 10 CFU/100 ml) and 37% fell within medium risk category (1 to 100 CFU/100 ml). A large proportion of test water samples (52.2%) fell within high risk category (101 to 1000). In addition, 26.1% test water samples were free of *Escherichia coli*, 21.7% fell within the low risk category (1 to 10 CFU/100 ml) and 47.8% fell within medium risk category (11 to 100 CFU/100

ml). A small proportion of test water samples (4.3%) fell within high risk (101 to 1000).

**Table 4.14: Classification of total coliforms and *Escherichia coli* in household untreated water samples**

Risk level category		Total coliforms		<i>Escherichia coli</i>	
		Frequency	Percent	Frequency	Percent
Valid	No Detection (ND)	3	6.5	12	26.1
	1–10	2	4.3	10	21.7
	11–100	17	37.0	22	47.8
	101–1000	24	52.2	2	4.3
	Total	46	100.0	46	100

## 4.6.2 Bacterial concentration after treatment by different HWT

### 4.6.1 Boiling method

Total coliforms and *Escherichia coli* in household water samples treated by boiling method ranged from 0 to 336 CFU/100 ml and from 0 to 79 CFU/100 ml, respectively. Log<sub>10</sub> total coliforms reduction ranged from -0.5 log<sub>10</sub> to 2.4 log<sub>10</sub>, which corresponded with -115.6% to 99.6% removal efficiency. Log<sub>10</sub> *Escherichia coli* ranged from -0.4 log<sub>10</sub> to 2.0 log<sub>10</sub> which corresponded with -200% to 100% removal efficiency. Gupta *et al.* (2007) found out that stored boiled drinking water was microbiologically unsafe for human consumption in the study of Indonesian tsunami survivors in Indonesia. High total coliforms and *Escherichia coli* concentrations in household treated water samples could have been due to prolonged storage of household drinking water and regrowth of total coliforms and *Escherichia coli*. Inappropriate water storage, dipping contaminated hands and cups into stored

drinking water also increase chances of high total coliforms and *Escherichia coli* concentrations in stored drinking water (Sobsey, 2002).

#### **4.6.2 Biosand filtration method**

Total coliforms and *Escherichia coli* concentrations in household water samples treated by biosand filtration method ranged from 9 to 106 CFU/100 ml and from 0 to 20 CFU/100 ml respectively. Log<sub>10</sub> total coliforms reduction ranged from -0.1 log<sub>10</sub> to 0.4 log<sub>10</sub>, which corresponded with -11.6% to 59.1% removal efficiency. Log<sub>10</sub> *Escherichia coli* reduction ranged from 0 log<sub>10</sub> to 0.6 log<sub>10</sub>, which corresponded with 0 to 75% removal efficiency. The present study does not support Stauber *et al* (2006), who found out that effectiveness of biosand filters on field tested water samples ranged from 0 log<sub>10</sub> to 2.5 log<sub>10</sub> (99.7%). The present study also doesn't support Earwaker (2006), who reported that biosand filters on average reduced *Escherichia coli* by 87.9% with 75.7% of filtrate samples with *Escherichia coli* <10 CFU/100 ml.

Poor performance of biosand filters could be due to their irregular use and poor maintenance. Most biosand filters looked not to have been in use for some time. Perhaps users re-started to use them when they heard about our research activities in their villages. For a biosand filter to effectively remove bacteria from drinking water, it should have been regularly used for more than 22 days. This explanation is supported by Sobsey *et al.* (2008) who reported that the efficacy of biosand filters in removing microbes in drinking water varied with filter maturity, dosing conditions,

flow rate, pause time between doses, grain size, and filter bed contact time. Inadequacies in biosand filter construction, operation and maintenance perhaps could further explain their poor performance in total coliforms and *Escherichia coli* removal. Earwaker (2006) reported that poor performance of biosand filters and low usage rates was attributed to the quality of maintenance, lack of reinforcement of educational messages and low support provided to filter users. Frisell *et al.* (2011) found out that poor performance of biosand filters were due to the fact that they had only been running for only two days at the time of testing, which is not adequate time for a schmutzdecke to form.

#### **4.6.3 Let it stand and settle method**

Total coliforms and *Escherichia coli* concentrations in household water samples treated by let it stand and settle method ranged from 12 to 360 CFU/100 ml and from 0 to 13 CFU/100 ml respectively. Log<sub>10</sub> total coliforms reduction ranged from -0.5 log<sub>10</sub> to 0.6 log<sub>10</sub>, which corresponded with -100 % to 73.5%. Log<sub>10</sub> *Escherichia coli* ranged from -0.6 log<sub>10</sub> to 0.0 log<sub>10</sub>, which corresponded with -300 to 0.0% removal efficiency. The present study supports UNCEF and WHO (2011) that found that treatment methods such as straining water through a cloth or let it stand and settle were inappropriate methods for household water treatment. Clasen and Boisson (2006) found out that total coliforms reduction treatment by let it stand and settle method resulted in total coliforms reduction mean 0.6 log<sub>10</sub> (95% CI= -0.4 –1.5).

#### 4.6.4 Aqua safe tablets

Total coliforms concentrations in household water samples treated by application of aqua safe tablets ranged from 0 to 13 CFU/100 ml.  $\log_{10}$  total coliforms reduction ranged from 0.0  $\log_{10}$  to 0.2  $\log_{10}$  which corresponded with 0 to 32% removal efficiency.  $\log_{10}$  *Escherichia coli* were 1.2  $\log_{10}$ , which corresponded with 100% removal efficiency. Lule *et al.* (2005) found out that majority of chlorine household treated water samples in the comparison study site had high *Escherichia coli* contamination than in the intervention study site. Ercumen *et al.* (2015) found out that majority of households had higher *Escherichia coli* counts in their stored water than their source water, indicating 77% in the controlled study site, 56% in the study site supplied with safe storage containers, 38% in the study site supplied with sub-optimal chlorine (<0.2 mg/l) and 14% in the study site supplied optimal chlorine ( $\geq 0.2$  mg/L). Poor total coliform and *Escherichia coli* removal efficiency by application of aqua safe tablets could be due to users' ignorance about the right procedure when disinfecting drinking water.

Overall, 23.9% and 19.5% of paired household water samples yielded negative  $\log_{10}$  total coliform and *Escherichia coli* reductions respectively. Negative log reduction occurs when bacteria concentration in a treated water sample is higher than it was before treatment (Brown & Sobsey, 2012). In the present study, negative log reduction perhaps resulted from poor handling of drinking water during storage, use of unsafe water storage options, inadequate cleaning of household water storage vessels and prolonged storage of drinking water. Mwabi *et al.* (2012) reported that



negative log reductions may result from regrowth of injured bacteria which at a later time their metabolism get reconstructed and recover their growth. Mellor *et al.* (2013) reported that improper handling of drinking water during storage, dipping dirty hands and cups into stored drinking water and ineffective cleaning of water storage containers increase chances of storage water contamination.

Research study by John *et al.* (2014) found out that earthen pots (water storage options) that had dirty rims and consumers rarely washed either their hands before taking water from the storage vessel were associated with high total coliforms concentration. Additionally, some coliforms such as *Escherichia coli* can enter a dormant state but viable thus when raw water is tested, they may not be detected or detected in low numbers. After their dormancy period, they are detected in large numbers than before. This interpretation is in line with that of Wu *et al.* (2002) which state that *Escherichia coli* and *V. cholerae* can enter a dormant state, in which they are viable but not culturable in media used for their detection.

#### **4.7 Testing hypothesis II**

The paired samples T-test was used to test the null hypothesis of no significant difference between bacteria counts in household drinking water samples before and after treatment. The analysis showed a significant difference between CFU of total coliforms before treatment ( $M = 152.4$ ,  $SD = 115.2$ ) and after treatment ( $M = 78$ ,  $SD = 93.3$ );  $t(45) = 4.4$ ,  $p = 0.000$ . Additionally, there was a significant difference between CFU of *Escherichia coli* before treatment ( $M = 38.5$ ,  $SD = 49.4$ ) and after treatment ( $M = 11$ ,  $SD = 17.7$ );  $t(45) = 3.79$ ,  $p = 0.000$  (Tables 4.15 and 4.16).

Therefore we reject the null hypothesis which stipulates, there are no significant differences between colony forming units in household water samples before and after treatment and accept the alternative hypothesis. These results indicate that household water treatment really reduces bacterial contaminants in household drinking water.

**Table 4.15: Paired samples statistics between bacteria counts in household water samples before and after treatment**

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Total coliforms (BT)	152.435	46	115.1983	16.9851
	Total coliforms (AT)	78.065	46	93.3391	13.7621
Pair 2	<i>Escherichia coli</i> (BT)	38.587	46	49.4645	7.2931
	<i>Escherichia coli</i> (AT)	11.000	46	17.7626	2.6190

**Table 4.16: Paired samples test between bacteria counts in household water samples before and after treatment**

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Total coliforms (BT) - Total coliforms (AT)	74.37	114.06	16.8176	40.49	108.24	4.42	45	.000
Pair 2	<i>Escherichia coli</i> (BT) – <i>Escherichia coli</i> (AT)	27.59	49.31	7.2704	12.94	42.23	3.79	45	.000

## 4.8 Effectiveness of HWT used under laboratory conditions

### 4.8.1 Bacteriological characteristics experiment test water samples before treatment

Table 4.17 shows the concentration of total coliforms and *Escherichia coli* in untreated experiment test water samples. Both total coliforms and *Escherichia coli* were above the limits as per WHO (2006) and UNBS (2008) guidelines for safe drinking water.

**Table 4.17: Concentration of bacterial counts before treatment**

Tested drinking water sources	Total coliforms (CFU/100 ml)	<i>Escherichia coli</i> (CFU/100 ml)
Hamwaro spring (KMS2)	190	20
Hamwaro spring (RWA1)	68	13
Mukakyenye spring (KMS1)	191	27
Sapato spring (KAT1)	56	12

Table 4.18 shows the frequencies and percentages of untreated experiment test water samples falling under different risk level categories. For total coliforms, samples were equally distributed into two risk category levels; medium risk category (11 to 100 CFU/100 ml) and high risk (101 to 1000). For *Escherichia coli*, all the samples fell within medium risk category (11 to 100 CFU/100 ml) when tested.

**Table 4.18: Classification of total coliforms and *Escherichia coli* in untreated experiment test water samples**

Risk level category		Total coliforms		<i>Escherichia coli</i>	
		Frequency	Percent	Frequency	Percent
Valid	11–100	10	50.0	20	100.0
	101–1000	10	50.0	0	0
	Total	20	100.0	20	100

#### 4.8.2 Bacteriological characteristics treated water samples by different HWT

Sobsey (2002) reported that several HWT have been developed to improve drinking water quality and reduce waterborne diseases. Nevertheless little has been reported with regards to their efficiency in removing total coliforms and *Escherichia coli* from drinking water sources. An ideal treatment technology should be able to remove or reduce all microbial contaminants to acceptable levels recommended by authorized bodies such as WHO and UNBS for the case of Uganda. In this study, the efficiency of HWT (boiling, biosand filtration, WaterGuard tablets, aqua safe tablets and let it stand and settle) in removing total coliforms and *Escherichia coli* from water was determined under laboratory conditions as indicated in the subsequent subsections;

##### 4.8.2.1 Boiling method

Table 4.19 illustrates the performance of boiling method in removing total coliforms and *Escherichia coli*. Total coliforms and *Escherichia coli* ranged from 0 to 3 CFU/100 ml and from 0 to 1 CFU/100 ml, respectively. Log<sub>10</sub> total coliforms reduction ranged from 1.7 log<sub>10</sub> to 2.3 log<sub>10</sub>, which corresponded with 98.4 to 100% removal efficiency. Log<sub>10</sub> *Escherichia coli* reduction ranged from 1.1 log<sub>10</sub> to 1.3 log<sub>10</sub>, which corresponded with 95 to 100% removal efficiency. High removal efficiency by boiling method could be due to heating water to a relatively high temperature (100°C), which has the potential to kill microorganisms in the heated water. Clasen *et al.* (2008) found out that heating drinking water to even 55°C has been shown to kill or inactivate most pathogenic bacteria, viruses and protozoa that

are commonly waterborne. Kazmi and Khan (2013) found out that heating water at 80°C kills pathogenic bacteria in water. Kazmi and Khan (2013) further noted that none of pathogenic bacteria including *Escherichia coli* were observed when water boiled up to 80°C.

**Table 4.19: Total coliforms and *Escherichia coli* counts in test water samples after boiling**

Water Sample	After treatment		Log <sub>10</sub> reductions		Percentage removal (%)	
	Total coliforms (CFU/100 ml)	<i>E.coli</i> (CFU/100 ml)	Total coliforms	<i>E.coli</i>	Total coliforms	<i>E.coli</i>
KMS2	3	1	1.8	1.3	98.4	95
RWA1	ND	ND	1.8	1.1	100	100
KMS1	1	ND	2.3	1.4	99.5	100
KAT1	ND	ND	1.7	1.1	100	100

#### 4.8.2.2 Biosand filtration method

Table 4.20 illustrates the performance of biosand filtration method in removing total coliforms and *Escherichia coli*. Total coliforms ranged from 0 to 40 CFU/100 ml after treatment. Log<sub>10</sub> total coliforms reduction ranged from 0.6 log<sub>10</sub> to 1.8 log<sub>10</sub>, which corresponded with 79.1 to 100% removal efficiency. There was no *Escherichia coli* detected per 100 ml after filtration by biosand. Log<sub>10</sub> *Escherichia coli* reduction ranged from 1.1 log<sub>10</sub> to 1.4 log<sub>10</sub>, which corresponded to 100% removal efficiency. The present study partially supports Vanderzwaag *et al.* (2009), who reported that average log reductions were 1.7 (98%) for total coliforms and 1.4 (96%) for *Escherichia coli*. Stauber *et al.* (2011) reported that when analysis of biosand filters was restricted to samples that had higher *Escherichia coli*

concentrations, removals greater than 99% were measured. Mahmood *et al.* (2011) found out that the mean *Escherichia coli* and total coliforms after biosand filtration was nearly 96% reductions. In addition, the findings of the current study do not support Baumgartner (2006) who found out that the average bacteria removal by biosand filtration method under laboratory conditions was 96.5%.

Stauber *et al.* (2006) found out that the geometric mean reductions of *Escherichia coli* by the biosand filter were 97% and 91% in laboratory experiments 1 and 2, respectively. In both experiments, the lowest *Escherichia coli* reductions were found during initial days of filter dosing. The minimum *Escherichia coli* reduction in experiment 1 was 1.2 log<sub>10</sub> (93%) measured on day 4 and in experiment 2, it was 0.4 log<sub>10</sub> (or 63%) measured on day 3. Maximum log<sub>10</sub> reduction of *Escherichia coli* in experiment 1 and 2 were 2.0 log<sub>10</sub> (99%) and 1.9 log<sub>10</sub> (98.9%). Generally, total coliform and *Escherichia coli* removal efficiency by biosand filtration method might be due to the biological layer formed on the top of the filter. Tellen *et al.* (2010) report that after 65 days, average percentage reductions in total coliform, fecal coliform and fecal streptococci were 98.9% for traditional biosand filters and 99% for the improved biosand filters. The study further reported that both modifications showed statistically significant improvements.

**Table 4.20: Total coliform and *Escherichia coli* counts in tested water samples after biosand filtration**

Water Sample	After treatment		Log <sub>10</sub> reduction		Percentage removal	
	Total coliforms (CFU/100 ml)	<i>E.coli</i> (CFU/100 ml)	Total coliforms	<i>E.coli</i>	Total coliforms	<i>E.coli</i>
KMS2	28	ND	0.8	1.3	85.3	100
RWA1	17	ND	0.6	1.1	75	100
KMS1	40	ND	0.7	1.4	79.1	100
KAT1	ND	ND	1.8	1.1	100	100

#### 4.8.2.3 WaterGuard tablets

Table 4.21 shows the performance of WaterGuard tablets in removing total coliforms and *Escherichia coli*. The concentration of total coliforms ranged from 0 to 4 CFU/100 ml after treatment. Log<sub>10</sub> total coliforms reduction ranged from 1.7 log<sub>10</sub> to 2.3 log<sub>10</sub>, which corresponded with 97.9 to 100% removal efficiency. There was no *Escherichia coli* detected per 100 ml after treatment. Therefore, log<sub>10</sub> *Escherichia coli* were just a function of the measured *Escherichia coli* in untreated water samples only.

In a related study, WaterGuard tablets proved significantly more effective than other water treatment methods such as PUR and filters to produce drinking water under the detection limit (<1 CFU/100 ml) across all water sources. The study further reported that when homes were assigned WaterGuard tablets, 51% of stored drinking water samples had *Escherichia coli* <1 CFU/100 ml (95% CI: 46–56%). When the same households were provided PUR, it was noted that 33% had *Escherichia coli*

concentrations <1 CFU/100 ml, and when provided filters, 39% had *Escherichia coli* <1 CFU/100 ml (Albert, Luoto, & Levine, 2010).

**Table 4.21: Total coliform and *Escherichia coli* counts in tested water samples after application of WaterGuard tablets**

Water Sample	After treatment		Log <sub>10</sub> reduction		Percentage removal	
	Total coliforms (CFU/100 ml)	<i>E.coli</i> (CFU/100 ml)	Total coliforms	<i>E.coli</i>	Total coliforms	<i>E.coli</i>
KMS2	ND	ND	2.3	1.3	100	100
RWA1	ND	ND	1.8	1.1	100	100
KMS1	4	ND	1.7	1.4	97.9	100
KAT1	ND	ND	1.8	1.1	100	100

#### 4.8.2.4 Aqua safe tablets

Table 4.22 illustrates the performance of aqua tablets in removing total coliforms and *Escherichia coli*. The concentration of total coliforms ranged from 1 to 2 CFU/100 ml after treatment. Log<sub>10</sub> total coliforms reduction ranged from 1.5 log<sub>10</sub> to 2.3 log<sub>10</sub>, which corresponded with 96.4 to 100% removal efficiency. There was no *Escherichia coli* detected per 100 ml after treatment. Therefore, log<sub>10</sub> *Escherichia coli* reductions were just a function of the measured *Escherichia coli* in untreated water samples only.



**Table 4.22: Total coliform and *Escherichia coli* counts in tested water samples after application of aqua safe tablets**

Water Sample	After treatment		Log <sub>10</sub> reduction		Percentage removal	
	Total coliforms (CFU/100 ml)	<i>E.coli</i> (CFU/100 ml)	Total coliforms	<i>E.coli</i>	Total coliforms	<i>E.coli</i>
KMS 2	ND	ND	2.3	1.3	100	100
RWA 1	ND	ND	1.8	1.1	100	100
KMS 1	1	ND	2.3	1.4	99.5	100
KAT 1	2	ND	1.5	1.1	96.4	100

#### 4.8.2.5 Let it stand and settle method

Table 4.23 illustrates the performance of aqua tablets in removing total coliforms. The concentration of total coliforms ranged from 40 to 62 CFU/100 ml after treatment. Log<sub>10</sub> total coliforms reduction ranged from -0.0 log<sub>10</sub> to 0.7 log<sub>10</sub>, which corresponded with -12.5 to 78.9% removal efficiency. The concentration of *Escherichia coli* ranged from 4 to 32 CFU/100 ml after treatment. Log<sub>10</sub> *Escherichia coli* reductions ranged from -0.2 log<sub>10</sub> to 0.5 log<sub>10</sub>, which corresponded with -60 to 70.4% removal efficiency.

Negative log<sub>10</sub> reductions observed were as a result of regrowth of bacteria in stored drinking water during the process of treatment. The study findings concur with the study by UNCEF and WHO (2011) which reported that HWT such as straining water through a cloth or let it stand and settle are considered inappropriate for household water treatment.

**Table 4.23: Total coliforms and *Escherichia coli* counts in tested water samples after treatment by let it stand and settle method**

Water Sample	After treatment		Log <sub>10</sub> reduction		Percentage removal	
	Total coliforms (CFU/100 ml)	<i>E.coli</i> (CFU/100 ml)	Total coliforms	<i>E.coli</i>	Total coliforms	<i>E.coli</i>
KMS2	40	32	0.7	-0.2	78.9	-60
RWA1	60	6	0.1	0.3	11.8	53.9
KMS1	51	8	0.6	0.5	73.3	70.4
KAT1	62	4	-0.0	0.3	-12.5	66.7

In both household and experiment water testing, the calculation of log<sub>10</sub> reduction was limited by non-detection of total coliforms and *Escherichia coli* in test water samples whose concentration was <1 CFU/100 ml. This means that log<sub>10</sub> reduction value was just a function of the measured total coliform and *Escherichia coli* in test water sample before treatment.

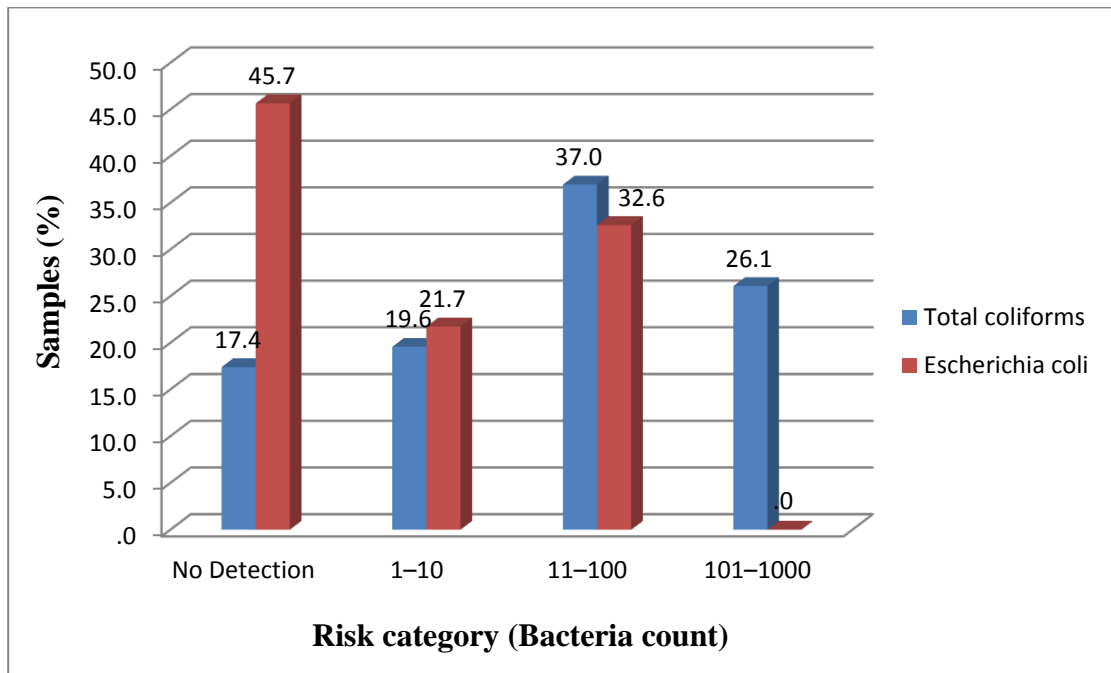
#### 4.9 Classification of test water samples after treatment

Classification of total coliforms and *Escherichia coli* in drinking water is critical since it fore tells the health risk level associated with drinking water that is microbiologically contaminated. WHO (2006) and UNBS (2008) require no total coliforms and *Escherichia coli* detected in 100 ml of any drinking water. By this declaration, samples that had no detectable total coliforms and *Escherichia coli* were fit for drinking whereas those whose concentration was >1 CFU/100 ml were not fit drinking by human beings. The presence of total coliforms and *Escherichia coli* indicate the possibility of pathogenic bacteria in water source and therefore its consumption may be disastrous to human life. In treated water samples, the

presence of both total coliforms and *Escherichia coli* may indicate inefficiency or failure of treatment applied (Figueras & Borrego, 2010).

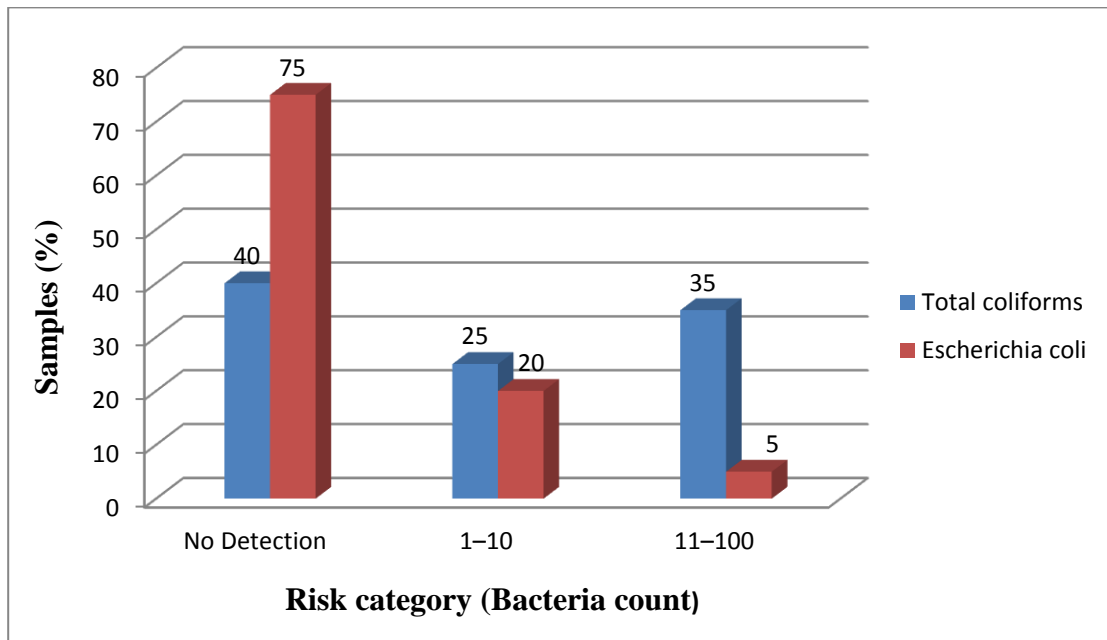
Figures 4.14 and 4.15 illustrate the percentages of treated water samples falling under risk categories for total coliforms and *Escherichia coli* contamination: 0 CFU/100 ml (in compliance), 1 to 10 CFU/100 ml (low risk), and 11 to 100 (medium risk) and 101 to 1000 (high risk).

In household treated water samples, 17.4% of water samples were free of total coliforms and 19.6% fell within the low risk category (1–10 CFU/100 ml). A big proportion (35%) fell within medium risk (11 to 100 CFU/100 ml) and 26.1% fell within high risk (101 to 1000). In addition, 45.7% of water samples were free of *Escherichia coli*, 21.7% fell within the low risk category (1–10 CFU/100 ml) and 32.6% fell within medium risk (11 to 100 CFU/100 ml). In related study, it was found that 54.1% of biosand filtered water at household level achieved the WHO guideline value of 0 CFU per 10 ml (Earwaker, 2006). Duke *et al.* (2006) found out that 80% of filtered water samples had no *Escherichia coli* per 100 ml and 17% were within low risk category (1 to 10 CFU/100 ml). In a related study, Stevenson (2008) found out that all test water samples that were treated by WaterGuard and aqua tabs had bacteria counts < 10 CFU/100 ml (low risk category).



**Figure 4.14: Bar graph showing the percentage of test water samples under different risk level categories in household testing**

In contrast, majority of experiment treated water samples (40%) were free of total coliforms. A small proportion (25%) fell within the low risk category (1 to 10 CFU/100 ml), 32.6% fell within medium risk category (11 to 100 CFU/100 ml) and 35% fell within high risk category (101 to 1000 CFU/100 ml). In addition, a large (73%) of water samples were free of *Escherichia coli* and 20% fell within the low risk category (1 to 10 CFU/100 ml). A small proportion (5%) fell within medium risk (11 to 100 CFU/100 ml). Figure 4.17 clearly illustrates this distribution according to risk level category. Brown and Sobsey (2012) reported that 44% of boiled samples had no detectable *Escherichia coli* (< 1 CFU/100 ml) and 73% had *Escherichia coli* < 10 CFU/100 ml.



**Figure 4.15: Bar graph showing the percentage of test water samples under different risk level categories in experiment testing**

#### **4.10 Comparison between household and experiment test results**

Generally, household treated samples recorded high concentrations of both total coliforms and *Escherichia coli* which eventually led to considerable low log reductions. Most of household treated water samples did not conform to WHO (2006) and UNBS (2008) guidelines for microbial drinking water quality. Mean  $\log_{10}$  total coliforms removal in household water samples were as follows; 0.7  $\log_{10}$  (40.1) for boiling method, 0.2  $\log_{10}$  (23.7%) for biosand filtration method, -0.01  $\log_{10}$  (-18.1%) for let it stand and settle method and 0.1  $\log_{10}$  (16%) for application of aqua safe tablets (Table 4.24). In addition, mean  $\log_{10}$  *Escherichia coli* removal in household water samples were as follows; 0.6  $\log_{10}$  (22.6 %) for boiling method, 0.3  $\log_{10}$  (37.5%) for biosand filtration method, -0.4  $\log_{10}$  (-200%) for let it

stand and settle method and 0.6 log<sub>10</sub> (50%) for application of aqua safe (Table 4.20). Although treatment by application of aqua safe tablets and boiling showed a slight higher *Escherichia coli* and total reduction than other treatment technologies, the observed differences in effectiveness were significantly small. Results showed a marginally greater performance by two treatment methods in removing total coliforms and *Escherichia coli* thus did not strongly indicate that one of the tested methods is more effective than others.

In contrast, water treatment by household technologies during experimentation recorded a remarkable decrease in both total coliform and *Escherichia coli* concentrations though a few of them achieved complete removal of *Escherichia coli* as required by WHO (2006) and UNBS (2008) guidelines for drinking water quality. There was no treatment technology that achieved complete removal of total coliforms. Mean log<sub>10</sub> total coliforms removal values achieved were 2 log<sub>10</sub> (98.9%) for boiling method, 0.9 log<sub>10</sub> (84.8%) for biosand filtration method 0.5 log<sub>10</sub> (38.3%) for let it stand and settle method, 1.9 log<sub>10</sub> (99.5%) for application of WaterGuard tablets, 2 log<sub>10</sub> (98.1%) for application of aqua safe tablets. The mean log<sub>10</sub> *Escherichia coli* removal values were 1.2 log<sub>10</sub> (98.8%) for boiling method, 1.2 log<sub>10</sub> (100%) for biosand filtration method, 0.5 log<sub>10</sub> (32.8%) for let it stand and settle method, 1.2 log<sub>10</sub> (100%) for application of WaterGuard tablets, 1.2 log<sub>10</sub> (100%) for application of aqua safe tablets (Table 4.25).

On the basis of average percentage removal efficiency of tested HWT under laboratory conditions, the present study concluded that the order of effectiveness

against total coliforms by HWT was observed to be; (i) application of WaterGuard tablets, (ii) boiling method, (iii) application of aqua safe, (iv) biosand filtration method, and (v) let it stand and settle method. The order of effectiveness against *Escherichia coli* by HWT was observed to be; (i) application of WaterGuard tablets = biosand filtration method and application of aqua safe, (ii) boiling method, and (iii) let it stand and settle method.

**Table 4.24: Mean log<sub>10</sub> bacteria reductions in household test water samples**

HWT	Log <sub>10</sub> total coliforms reduction	Total coliforms reduction (%)	Log <sub>10</sub> <i>Escherichia coli</i> reduction	<i>Escherichia coli</i> reduction (%)
Boiling method	0.7	40.1	0.6	22.6
Biosand filtration method	0.2	23.7	0.3	37.5
Let it stand and settle method	-0.01	-18.1	-0.4	-200
Aqua safe tablets	0.1	16	0.6	50
Total	0.2	19.4	0.3	-22.5

**Table 4.25: Mean log<sub>10</sub> bacteria reductions in experiment test water samples**

HWT	Log <sub>10</sub> total coliforms reduction	Total coliforms reduction (%)	Log <sub>10</sub> <i>Escherichia coli</i> reduction	<i>Escherichia coli</i> reduction (%)
Boiling method	2	98.9	1.2	98.8
Biosand filtration method	0.9	84.8	1.2	100
Let it stand and settle method	0.5	38.3	0.5	32.8
WaterGuard tablets	1.9	99.5	1.2	100
Aqua safe tablets	2	98.9	1.2	100
Total	1.5	84.1	1.1	86.6

### 4.11 Testing hypothesis III

A one-way analysis of variance was conducted to test the null hypothesis of no significant differences between mean bacteria reductions by different HWT under laboratory conditions. The independent variable was HWT with five levels; boiling method, biosand filtration method, let it stand and settle method, application of WaterGuard tablets and aqua safe tablets. The dependent variables were mean  $\log_{10}$  total coliforms and *Escherichia coli* reductions per 100 ml. ANOVA tests yielded significant variations among mean  $\log_{10}$  total coliforms reduction,  $F(4, 15) = 14.1$ ,  $P = 0.000$  and mean  $\log_{10}$  *Escherichia coli* reduction,  $F(4, 15) = 5.7$ ,  $P = 0.006$  (Table 4.26). Therefore, we reject the null hypothesis which stipulates, there are no significant differences between mean reductions by different HWT under laboratory conditions and accept the alternative hypothesis.

**Table 4.26: ANOVA results showing the relationship between  $\log_{10}$  reduction by HWT in experiment test water samples**

		Sum of Squares	df	Mean Square	F	Sig.
Log <sub>10</sub> total coliform reduction	Between Groups	7.8	4	1.9	14.1	.000
	Within Groups	2.1	15	1.1		
	Total	9.8	19			
Log <sub>10</sub> <i>Escherichia coli</i> reduction	Between Groups	1.8	4	0.5	5.7	.006
	Within Groups	1.2	15	0.1		
	Total	3.0	19			

Post hoc Tukey tests were conducted across  $\log_{10}$  total coliforms and *Escherichia coli* reductions by different HWT to determine whether there were no significant differences between mean  $\log_{10}$  total coliforms and *Escherichia coli* reductions in



experiment test water samples (Appendances IV and V). Results are discussed in the subsequent section.

Analysis showed significant differences in  $\log_{10}$  total coliforms reduction between boiling and the other four treatment technologies ( $P < 0.05$ ), except when  $\log_{10}$  total coliforms reduction by boiling was compared with  $\log_{10}$  total coliform reduction by application of WaterGuard tablets and application of aqua safe tablets ( $P > 0.05$ ). Significant differences in  $\log_{10}$  total coliforms reduction were observed between treatment by biosand filtration and other four HWT ( $P < 0.05$ ), except when  $\log_{10}$  total coliforms reduction by biosand filtration was compared with  $\log_{10}$  total coliforms reduction by let it stand and settle and application of WaterGuard tablets ( $P > 0.05$ ).

Additionally, results indicated significant differences in  $\log_{10}$  total coliforms reduction between treatment by let it stand and settle method and other four water treatment technologies ( $P < 0.05$ ), except when  $\log_{10}$  total coliforms reduction by let it stand and settle method was compared with  $\log_{10}$  total coliforms reduction by biosand filtration method ( $P > 0.05$ ). Significant differences were observed in  $\log_{10}$  total coliforms reduction between application of WaterGuard tablets and other four HWT ( $P < 0.05$ ), except when  $\log_{10}$  total coliforms reduction by application of WaterGuard tablets was compared with  $\log_{10}$  total coliforms reduction by boiling and application of aqua safe tablets ( $P > 0.05$ ). Furthermore, results indicate significant differences in  $\log_{10}$  total coliforms reduction between treatment by application of aqua safe tablets and the other four HWT ( $P < 0.05$ ), except when

$\log_{10}$  total coliforms reduction by application of aqua safe tablets was compared with  $\log_{10}$  total coliforms reduction by application of WaterGuard tablets and boiling method ( $P > 0.05$ ).

Additionally, there was no significant differences in  $\log_{10}$  *Escherichia coli* reduction between boiling and the other four HWT ( $P > 0.05$ ), except when  $\log_{10}$  *Escherichia coli* reduction by boiling method was compared with  $\log_{10}$  *Escherichia coli* reduction by let it stand and settle method ( $P > 0.05$ ). The study results showed no significant differences in  $\log_{10}$  *Escherichia coli* reduction between biosand filtration and other four HWT ( $P > 0.05$ ), except when  $\log_{10}$  *Escherichia coli* reduction by biosand filtration was compared with  $\log_{10}$  *Escherichia coli* reduction by let it stand and settle method ( $P < 0.05$ ). Additionally results indicate significant differences in  $\log_{10}$  *Escherichia coli* reduction between let it stand and settle method and other four HWT ( $P < 0.05$ ). No significant differences were observed in  $\log_{10}$  *Escherichia coli* reduction between application of WaterGuard tablets and other four HWT ( $P > 0.05$ ), except when  $\log_{10}$  *Escherichia coli* reduction by application of WaterGuard tablets was compared with  $\log_{10}$  *Escherichia coli* reduction by let its stand and settle method ( $P < 0.05$ ). Additionally, results indicated no significant differences in  $\log_{10}$  *Escherichia coli* reduction by application of aqua safe tablets and other four HWT ( $P > 0.05$ ), except when  $\log_{10}$  *Escherichia coli* reduction by application of aqua safe tablets was compared with  $\log_{10}$  *Escherichia coli* reduction by let it stand and settle method ( $P < 0.05$ ).

Although a gradual removal of total coliforms by all the tested HWT was noted after treatment of test water samples, treatment by application of WaterGuard tablets significantly demonstrated a greater performance compared to the other four HWT. It was able to reduce the concentration of total coliforms yielding a mean log reduction value of  $1.9 \log_{10}$  which corresponded with 99.5% removal efficiency. Mean  $\log_{10}$  *Escherichia coli* reduction by application of WaterGuard tablets was  $1.2 \log_{10}$ , which corresponded with 100% removal efficiency. Treatment by boiling, biosand filtration, application of WaterGuard tablets and application of aqua safe tablets significantly demonstrated greater performance in removing *Escherichia coli* in source water samples with mean  $\log_{10}$  reduction value of  $1.2 \log_{10}$  which corresponded with 100% removal efficiency.

## **CHAPTER 5: SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS**

### **5.1 Introduction**

This chapter presents the summary of the main findings, conclusion, recommendations of the study and areas for further research. The general objective of the study was to examine HWT and evaluate their ability to improve the microbial quality of drinking water at household level in Kabale District, southwestern Uganda. The specific objectives of the study were to: (i) evaluate the different water sources, household water treatment technologies, and storage options of household drinking water, (ii) to establish whether the source of drinking water influences the type of water treatment technology used at household level, (iii) to determine whether there is significant difference between bacterial counts in household drinking water samples before and after treatment and (iv) to evaluate bacteriological effectiveness of HWT used under laboratory conditions. Tools used to conduct the study were semi structured questionnaires, field observations and water analysis. Data analysis tools were mainly descriptive statistics. Parametric tests such as paired T-test, one way ANOVA and chi-square were used.

### **5.2 Summary of findings**

A total of 205 respondents were interviewed during unannounced field study visits. Majority of the households (61.5%) reported they were using water springs as their primary source of drinking water. Other water sources were public and private water

taps, shallow wells and boreholes. At least 75.6% of the households were practicing household water treatment. HWT reported were; boiling, application of aqua safe tablets, let it stand and settle method, biosand filtration method and application of WaterGuard tablets. The study further reported that 72.2% households were storing drinking water using any storage container. 5-liter jerricans, plastic buckets, 20-liter jerricans, jugs, kettles and flasks were repeatedly reported household water storage options during the field study visits. Of the 46 households that had stored treated drinking water, 71.7% were using narrow-mouthed water storage containers whereas 28.3% were using wide mouthed water storage containers respectively. The study revealed no significant relationship between drinking water sources and the type of household water treatment technologies ( $P > 0.05$ ).

In household water testing, boiling method recorded a slightly higher percentage removal of total coliforms with a mean value of 28.2% ( $0.6 \log_{10}$ ), followed by biosand filtration method with 23.8% ( $0.2 \log_{10}$ ), application of aqua safe tablets with 16% ( $0.1 \log_{10}$ ) and let it stand and settle method with -18.1% ( $-0.01 \log_{10}$ ). The study further revealed that treatment by application of aqua safe tablets recorded the highest percentage removal of *Escherichia coli* with a mean value of 50% ( $0.6 \log_{10}$ ), followed by biosand filtration method with 37.5% ( $0.3 \log_{10}$ ), boiling method with -23.3% ( $0.4 \log_{10}$ ) and let it stand and settle method with -200% ( $-0.4 \log_{10}$ ). It was further noted that majority of treated household water samples were associated with high bacteria counts compared to untreated household water samples.

In experiment water testing, application of WaterGuard tablets recorded the highest percentage removal of total coliforms with a mean value of 99.5% ( $1.9 \log_{10}$ ), followed by boiling method with 98.9% ( $2 \log_{10}$ ), application of aqua safe tablets with 98.1% ( $2 \log_{10}$ ), biosand filtration method with 84.8% ( $0.9 \log_{10}$ ) and let it stand and settle method with 38.3% ( $0.5 \log_{10}$ ). Treatment by application of WaterGuard tablets, biosand filtration method, application of aqua safe tablets recorded high percentage removal of *Escherichia coli* with a mean value of 100% ( $1.2 \log_{10}$ ), followed by boiling method with 98.8% ( $1.2 \log_{10}$ ) and let it stand and settle method with 32.8% ( $0.5 \log_{10}$ ). HWT significantly reduced total coliforms and *Escherichia coli* with exception of let it stand and settle method.

### 5.3 Conclusions

This study confirmed that majority households were using water springs as their sources of drinking water at household level. The observed homesteads and toilets located in close proximity to water springs were responsible for high total coliforms and *Escherichia coli* concentrations in water samples from water springs. Run offs from crop farms located in the shallow wells' upstream was responsible for the increased turbidity and sediment levels in most shallow wells.

This study also confirmed that majority respondents were practicing household water treatment with any one of the following technologies: boiling, biosand filtration, let it stand and settle, application of WaterGuard tablets and application of aqua safe tablets. Treatment by boiling method was reported the most popular water treatment

method, unlike treatment by biosand filtration, use of WaterGuard tablets, aqua safe tablets and let it stand and settle methods. Wide use of boiling method was due to availability of fuel wood.

From this study, it was found out that majority respondents who were boiling their drinking water were doing so because the method was cheap and easy to use. This was because of efforts by the government of Uganda to promote household health through access to safe drinking water. Though the uptake of biosand filtration method was significantly low, those who were using it believed that the method was easy to use, cost effective once installed and produces water ready for consumption. Majority respondents who were using let it stand and settle were doing so because the method is cheap. Use of aqua safe and WaterGuard tablets is significantly low more especially in rural areas. The efforts to promote wide use of WaterGuard and aqua safe tablets were hardly recognised on the ground.

Majority of household treated water samples were associated high bacteria contamination ( $>10\text{CFU}/100\text{ ml}$ ). High total coliforms and *Escherichia coli* concentrations in household treated water samples resulted from improper handling of stored drinking water, regrowth of bacteria, and accumulation of biofilm layer inside the storage containers.

A significant decrease in total coliforms and *Escherichia coli* concentrations occurred after treatment of contaminated source water samples by different HWT with exception of let it stand and settle method. Although none of the HWT

achieved complete removal (100%) of total coliforms, application of WaterGuard tablets was found to be the most efficient method in removing total coliforms from contaminated drinking water. Although some HWT did not significantly remove *Escherichia coli* from source contaminated drinking water, application of WaterGuard tablets, biosand filtration method and application of aqua safe achieved complete removal of *Escherichia coli*.

#### **5.4 Recommendations**

Based on the findings of this study, the following are the recommendations to the policy makers, NGOs and households in Kabale District to ensure access to safe drinking water.

- i. Spring water should be treated before drinking due to high total coliforms concentration which makes it unsafe for consumption. The responsibility to improve household drinking water must generally fall on individual households.
- ii. The government and NGOs should take an active role to promote effective household water treatment methods such as application of WaterGuard, application of aqua safe and biosand filtration method to replace less effective local methods such as let it stand and settle method, which is currently practiced in some communities.
- iii. Nowadays, there are available cheap water testing methods to evaluate the microbiological effectiveness of water treatment technologies. The local



people should always be involved in testing for microbiological effectiveness of recently introduced water treatment technologies in Kabale District.

### **5.5 Areas for further research**

Further research is needed in the following areas in Kabale District southwestern Uganda.

- i. Assessment of the impacts of household water treatment and storage on community health.
- ii. Effect of household water storage options on microbiological quality of drinking water.
- iii. Role of gender in household water treatment and promotion in Kabale District southwestern Uganda.

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## **APPENDICES**

### **APPENDIX I: Semi-structured questionnaire**

Greetings!

My name is Alex Saturday; I am a student of Kenyatta University pursuing Msc. Integrated Watershed Management. Currently I am conducting a study on: Examination of household water treatment technologies for microbial removal in Kabale District, south western Uganda. I plan to administer this questionnaire to 205 household heads or adults above the 18 years of age in this district. You have been selected by chance. I kindly request you to take part in this study.

The information you will give shall be confidential, neither shall I publish it in any newspapers nor be read on any radio or television. Only the study staff and investigators will know your answers to the questions.

Thanks!

Alex.

**Part A: Socio-economic and demographic characteristics**

No	Question	Coding			Instruction
01	Sex of respondents	Male	1		
		Female	2		
02	What is your marital status?	Married	1		
		Single Parent	2		
		Single	3		
		Divorced	4		
		Widowed	5		
03	How old are you?	18-25years	1		
		26-35 years	2		
		36-45 years	3		
		46-55years	4		
		56+ above	5		
04	What is your current occupation?	Salaried worker	1		
		Business person	2		
		Unemployed	3		
		Daily laborer	4		
		Farmer	5		
05	Does your spouse work as well?	Yes	1		Applicable if married
		No	2		
06	What is your educational level?	None	1		
		Primary	2		
		Secondary	3		
		Diploma	4		
		University	5		
07	What is your monthly family income?	10,000 - 200,000 UGX	1		
		200,000 - 400,000UGX	2		
		400,000 - 600,000UGX	3		
		600,000UGX+	4		

08	How many people live in your house?		Write down the number
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**Part B: Sources of drinking**

No.	Question	Coding		Instruction
01	What is your current main source of water?	Piped water into dwelling	1	
		Shallow wells	2	
		Lake	3	
		Piped water from a neighbor	4	
		Public tap	5	
		Bore hole	6	
		Protected springs	7	
		River	8	
		Unprotected springs	9	
		Other (specify)	10	
	If yes / no, state why? .....			
02	Is water normally available from this source?	Yes	1	
		No	2	
03	Who typically collects the water for the household?	Woman	1	
		Children (girls only)	2	
		Children (boys only)	3	
		Children (all)	4	
		Woman and children (girls)	5	
		Mother and Children (boys)	6	
		Man and Woman	7	
04	How often do you collect water?	Once a day	1	
		Twice a day	2	
		Thrice a day	3	

		4 times a day	4	
		5 times a day	5	
		More than 6 times	6	
05	What type of containers do you use to collect drinking water?	Jerry can	1	
		Bucket with lid	2	
		Bucket without lid	3	
		Sauce pan	4	

### Part C: Household water treatment and safe storage options

#### I. Household water treatment

No.	Question	Coding		Instruction
01	Do you do anything to make water safer to drink?	No	1	If no, move to qn. 6
		Yes	2	
02	Do you know what families can do to make water better for drinking in the house?	No	1	If yes, record all mentioned
		Yes	2	
03	How often do you treat your drinking water?	Rarely	1	
		Sometimes	2	
		Always	3	
04	Which method do you usually apply to make your water safer to drink?	Boil	1	
		Add chlorine tablets (Aquatabs)	2	
		Strain it through a cloth	3	
		Let it stand and settle	4	
		Filtration	5	
		Solar disinfection	6	
		Use water guard	7	
05	Why did you choose this method for making water safer?	Others (specify)	8	
		Cheap to use	1	
		Produces a large volume of safe drinking water	2	
		Requires less time	3	
		Ease to transport	4	

		Improves water taste	5	
		Makes water more Clear than before	6	
		Has passive health impact	7	
		I don't know others	8	
06	Why don't you treat your drinking water?	It's expensive	1	
		Bad taste and smelly of treated water	2	
		I believe water is safe from the source	3	
		We are used to drinking untreated water and nothing has happened to us	4	
		Other ( <i>specify</i> )	5	

## II. Household water storage

No.	Question	Coding		Instructi on
01	Do you usually store drinking water?	No	1	If no, move to Qn 07
		Yes	2	
02	Do you currently have stored water available from which I could collect a sample?	No	1	
		Yes	2	
03	Where do you store your drinking water?	Clay pot	1	
		Plastic bucket	2	
		Plastic bottle	3	
		Steel bucket	4	
		Vessel with a tap	5	
		Other (Specify)	6	
04	OBSERVE: Do the vessels have a narrow mouth or a closed mouth? Narrow mouth opening is 5 cm or less.	Narrow mouthed	1	
		Wide mouthed	2	
05	OBSERVE: Are the containers covered?	Not covered	1	

		Covered with hard cover	2	
		Half covered	3	
		Covered with soft covers	4	
06	How do you draw drinking water out of the storage container?	Dip with a cup	1	
		Pour into drinking cup directly from tap	2	
		Dip with a Ladle with a handle	3	
		Dip with bowl, cup, glass without handle	4	
		Other mechanism (specify)	5	
07	Does any hand or fingers sometimes touch water in the storage container?	No	1	
		Yes	2	
08	Why don't you store your drinking water?	The odor of stored water is bad	1	Extended from qn 1
		Storage containers usually don't last for long	2	
		I can't afford the cost of improved water storage vessels.	3	
		Others (specify)	4	
09	How long has your drinking water stayed in the storage container?	Less than a day	1	
		1 day	2	
		2 days	3	
		3 days	4	



		4 days	5	
		Older than 3 days	6	
10	From which source did you collect drinking water the last time you collected water? (Try to get a sample from the original source)			

## APPENDIX II: Concentration of bacteria in field tested water samples

Sample	T/C <sub>b</sub>	T/C <sub>a</sub>	T/C LR	T/C <sub>LR</sub> (%)	E.C b	E.C <sub>a</sub>	E.C LR	E.C LR (%)	HWT
KAT021	270	5	1.7	98.1	12	0	1.1	100	Boiling
KAT07	70	70	0	0	20	32	-0.2	-60	Boiling
KAT020	101	0	2	100	9	20	-0.4	-122.2	Boiling
KAT02	8	4	0.3	50	0	0	0	0	Boiling
KAT01	50	0	1.7	100	0	0	0	0	Boiling
KAT014	152	69	0.3	54.6	28	4	0.8	85.7	Boiling
KAT025	167	40	0.6	76	0	0	0	0	Boiling
KAT06	81	0	1.9	100	0	0	0	0	Boiling
KMS09	64	74	-0.1	-15.6	45	10	0.7	77.8	Boiling
KMS02 9	106	6	1.2	94.3	78	0	1.9	100	Boiling
KMS02 2	250	1	2.4	99.6	30	0	1.5	100	Boiling
KMS03 7	102	220	-0.5	-115.7	1	3	-0.4	-200	Boiling
KMS03 6	172	336	-0.3	-95.3	76	79	0	-3.9	Boiling
KMS04 3	304	57	0.7	81.3	242	15	1.2	93.8	Boiling
KMS05	112	73	0.2	43.8	55	70	-0.1	-27.3	Boiling
KMS02 1	324	6	1.7	98.1	34	0	1.5	100	Boiling
KMS04 1	266	122	0.3	54.1	134	7	1.3	95	Boiling
KMS04 8	215	59	0.6	72.6	5	12	-0.4	-140	Boiling
KMS01	43	0	1.6	100	35	0	1.5	100	Boiling
KMS01 1	126	250	-0.3	-98.4	72	26	0.4	64	Boiling
NYW04 4	134	202	-0.2	-50.7	63	16	0.6	74.6	Boiling
NYW09	67	50	0.1	25.4	12	11	0	8.3	Boiling

KMS03 1	496	162	0.5	67.3	131	18	0.9	86.3	Boiling
NYW01 6	26	30	-0.2	-50	8	8	0	0	Boiling
NYW04 3	0	3	-0.5	-100	1	3	-0.3	-200	Boiling
NYW02 5	91	12	0.9	86.8	32	0	1.5	100	Boiling
NYW02	242	120	0.3	50.4	28	19	0.2	32.1	Boiling
NYW04 8	89	116	-0.1	-23.3	0	0	0	0	Boiling
NYW01 3	195	104	0.3	46.7	42	0	1.6	10	Boiling
KMS04 1	266	122	0.3	54.1	134	7	1.3	95	Boiling
RWA06	322	202	0.2	37.3	0	20	0	-1.3	Boiling
RWA01 9	60	0	1.8	100	0	0	0	0	Boiling
RWA03 7	118	0	2.1	100	120	0	2.1	100	Boiling
RWA03 2	188	53	0.3	55.1	43	47	0	-9.3	Boiling
RWA02 4	306	200	0.2	34.3	45	0	1.7	100	Boiling
RWA05 3	226	226	0	0	0	0	0	0	Boiling
KMS04 2	321	12	1.4	96.3	66	0	1.8	100	Boiling
RWA03 8	232	0	2.4	100	53	0	1.7	0	Boiling
NYW05	132	35	0.6	73.5	0	3	-0.5	-300	Let it stand and settle method
NYW04 3	0	3	-0.5	-100	1	3	-0.3	-200	Let it stand and settle method
NYW36	340	360	0	-5.6	13	13	0	0	Let it stand and settle method
RWA04 2	42	59	-0.1	-40.5	10	40	-0.6	-300	Let it stand and settle method
NYW04 6	95	106	0	-11.6	80	20	0.6	75	Biosand filtration
NYW01 8	22	9	0.4	59.1	0	0	0	0	Biosand filtration
KAT018	19	13	0.2	32	17	0	1.2	100	Aqua Safe

									Tablets
KAT03	0	0	0	0	0	0	0	0	Aqua Safe Tablets

### APPENDIX III: Concentration of bacteria in experiment tested water samples

Sample	T/C <sub>b</sub>	T/C <sub>a</sub>	T/C <sub>LR</sub>	T/C <sub>LR</sub> (%)	E.C <sub>b</sub>	E.C <sub>a</sub>	E.C <sub>LR</sub>	E.C <sub>LR</sub> (%)	HWT
KMS2	190	0	2.3	100	20	0	1.3	100	Boiling
RWA1	68	0	1.8	100	13	0	1.1	100	Boiling
KMS1	191	1	2.3	99.5	27	0	1.4	100	Boiling
KAT1	56	2	1.7	96.4	12	0	1.1	100	Boiling
KMS2	190	28	0.8	85.3	20	0	1.3	100	Biosand filtration
RWA1	68	17	0.6	75	13	0	1.1	100	Biosand filtration
KMS1	191	40	0.7	79.1	27	0	1.4	100	Biosand filtration
KAT1	56	0	1.8	100	12	0	1.1	100	Biosand filtration
KMS2	190	0	2.3	100	20	0	1.3	100	WaterGuard tablets
RWA1	68	0	1.8	100	13	0	1.1	100	WaterGuard tablets
KMS1	191	4	1.7	97.9	27	0	1.4	100	WaterGuard tablets
KAT1	56	0	1.7	100	12	0	1.1	100	WaterGuard tablets
KMS2	190	0	2.3	100	20	0	1.3	100	Aqua safe tablets
RWA1	68	0	1.8	100	13	0	1.1	100	Aqua safe tablets
KMS1	191	1	2.3	99.5	27	0	1.4	100	aqua safe tablets
KAT1	56	2	1.7	96.4	12	0	1.1	100	Aqua safe tablets
KMS2	190	40	0.7	78.9	20	32	-0.2	-60	Let it stand and settle
RWA1	68	60	0.9	11.8	13	6	1.1	53.9	Let it stand and settle
KMS1	191	51	0.6	73.3	27	8	0.5	70.4	Let it stand and settle

KAT1	56	62	-0	-10.7	12	4	0.5	66.7	Let it stand and settle
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**APPENDIX IV: Multiple comparisons (a post hoc Tukey test) of log<sub>10</sub> total coliforms reduction by different HWT**

(I) HWT	(J) HWT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Boiling method	Biosand filtration method	1.067750 *	0.263029	0.008	0.25554	1.87996
	Let it stand and settle method	1.503000 *	0.263029	0	0.69079	2.31521
	Application of WaterGuard tablets	0.147775	0.263029	0.979	-0.66444	0.95999
	Application of aqua safe tablets	0	0.263029	1	-0.81221	0.81221
Bio-sand filtration method	Boiling method	-1.067750 *	0.263029	0.008	-1.87996	-0.25554
	Let it stand and settle method	0.43525	0.263029	0.488	-0.37696	1.24746
	Application of WaterGuard tablets	-.919975*	0.263029	0.023	-1.73219	-0.10776
	Application of aqua safe tablets	-1.067750 *	0.263029	0.008	-1.87996	-0.25554
Let it stand and settle method	Boiling method	-1.503000 *	0.263029	0	-2.31521	-0.69079
	Bio-sand filtration method	-0.43525	0.263029	0.488	-1.24746	0.37696
	Application of WaterGuard tablets	-1.355225 *	0.263029	0.001	-2.16744	-0.54301
	Application of aqua safe tablets	-1.503000 *	0.263029	0	-2.31521	-0.69079
Application of WaterGuard tablets	Boiling method	-0.14778	0.263029	0.979	-0.95999	0.66444
	Biosand filtration method	.919975*	0.263029	0.023	0.10776	1.73219
	Let it stand and settle method	1.355225 *	0.263029	0.001	0.54301	2.16744

	Application of aqua safe tablets	-0.14778	0.263029	0.979	-0.95999	0.66444
Application of aqua safe tablets	Boiling method	0	0.263029	1	-0.81221	0.81221
	Biosand filtration method	1.067750*	0.263029	0.008	0.25554	1.87996
	Let it stand and settle method	1.503000*	0.263029	0	0.69079	2.31521
	Application of WaterGuard tablets	0.147775	0.263029	0.979	-0.66444	0.95999

\*. The mean difference is significant at the 0.05 level.

#### **APPENDIX V: Multiple comparisons (a post hoc Tukey test) of log<sub>10</sub> *Escherichia coli* reduction by different HWT**

(I) HWT	(J) HWT	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Boiling method	Bio-sand filtration method	0	0.200251	1	-0.61836	0.61836
	Let it stand and settle method	.751750*	0.200251	0.014	0.13339	1.37011
	Application of WaterGuard tablets	-0.00225	0.200251	1	-0.62061	0.61611
	Application of aqua safe tablets	0	0.200251	1	-0.61836	0.61836
Bio-sand filtration method	Boiling method	0	0.200251	1	-0.61836	0.61836
	Let it stand and settle method	.751750*	0.200251	0.014	0.13339	1.37011
	Application of WaterGuard tablets	-0.00225	0.200251	1	-0.62061	0.61611
	Application of aqua safe tablets	0	0.200251	1	-0.61836	0.61836
Let it stand and settle method	Boiling method	-.751750*	0.200251	0.014	-1.37011	-0.13339
	Bio-sand filtration method	-.751750*	0.200251	0.014	-1.37011	-0.13339
	Application of WaterGuard tablets	-.754000*	0.200251	0.014	-1.37236	-0.13564
	Application of aqua	-	0.20025	0.01	-	-

	safe tablets	.751750 *	1	4	1.37011	0.1333 9
Application of WaterGuard tablets	Boiling method	0.00225	0.20025 1	1	- 0.61611	0.6206 1
	Bio-sand filtration method	0.00225	0.20025 1	1	- 0.61611	0.6206 1
	Let it stand and settle method	.754000 *	0.20025 1	0.01 4	0.13564	1.3723 6
	Application of aqua safe tablets	0.00225	0.20025 1	1	- 0.61611	0.6206 1
Application of aqua safe tablets	Boiling method	0	0.20025 1	1	- 0.61836	0.6183 6
	Bio-sand filtration method	0	0.20025 1	1	- 0.61836	0.6183 6
	Let it stand and settle method	.751750 *	0.20025 1	0.01 4	0.13339	1.3701 1
	Application of WaterGuard tablets	-0.00225	0.20025 1	1	- 0.62061	0.6161 1

\*. The mean difference is significant at the 0.05 level.

## APPENDIX VI: Research permit



### Uganda National Council for Science and Technology

(Established by Act of Parliament of the Republic of Uganda)

Our Ref: SIR 145

30<sup>th</sup> October 2015

Saturday Alex  
Kenyatta University  
Kenya

**Re: Research Approval:** Examining Household Water Treatment Technologies for Microbial Removal in Kabale district, South-Western Uganda

I am pleased to inform you that on **21/09/2015**, the Uganda National Council for Science and Technology (UNCST) approved the above referenced research project. The Approval of the research project is for the period of **21/09/2015 to 21/09/2016**.

Your research registration number with the UNCST is **SIR 145**. Please, cite this number in all your future correspondences with UNCST in respect of the above research project.

As Principal Investigator of the research project, you are responsible for fulfilling the following requirements of approval:

1. All co-investigators must be kept informed of the status of the research.
2. Changes, amendments, and addenda to the research protocol or the consent form (where applicable) must be submitted to the designated Research Ethics Committee (REC) or Lead Agency for re-review and approval prior to the activation of the changes. UNCST must be notified of the approved changes within five working days.
3. For clinical trials, all serious adverse events must be reported promptly to the designated local REC for review with copies to the National Drug Authority.
4. Unanticipated problems involving risks to research subjects/participants or other must be reported promptly to the UNCST. New information that becomes available which could change the risk/benefit ratio must be submitted promptly for UNCST review.
5. Only approved study procedures are to be implemented. The UNCST may conduct impromptu audits of all study records.
6. A progress report must be submitted electronically to UNCST within four weeks after every 12 months. Failure to do so may result in termination of the research project.

Below is a list of documents approved with this application:

	Document Title	Language	Version	Version Date
1	Research Proposal	English	N/A	April 2015
2	Questionnaire	English	N/A	April 2015

Yours sincerely,

  
Hellen .N. Opolot  
for: Executive Secretary  
UGANDA NATIONAL COUNCIL FOR SCIENCE AND TECHNOLOGY

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