Microbiological drinking water quality and prevalence of waterborne diseases in Masaka, Rwanda

Submitted in fulfilment of the requirements for the degree of Master of Technology degree: Environmental Health in the Faculty of Health Sciences at the Durban University of Technology

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ABSTRACT

Waterborne diseases represent substantial global burden of disease and children under the age of five are more susceptible to these diseases compared to adults. The aim of this study was to determine the microbiological quality of Nyabarongo River water used for domestic purposes, women's knowledge, attitudes and practices (KAP) on water usage and waterborne diseases and its link to the diarrhoea outbreaks experienced in two rural communities: Rusheshe and Ayabaraya of Masaka in Rwanda.

A total of 35water samples were collected from Nyabarongo River and from study households which used slow sand filtration (SSF) or Sûr'Eau as treatment methods and analyzed for total coliform and faecal coliform indicators. For household samples turbidity was also analyzed. Retrospective records from Masaka Health Centre were reviewed to determine the prevalence of waterborne diseases from the study areas during 2010. Further, a structured questionnaire was administered to 324 women residents of the study areas to elicit information on their KAP on water handling and waterborne diseases. SPSS Predictive Analytic Software (PASW) Statistics version 18.0 (IBM, Somers, NY) and STATA Release (Version 11.0, College Station, Texas USA) were used for data analysis.

Results showed that the mean values of total and faecal coliforms of river and household water samples were above the WHO and Rwandan recommended guidelines. The mean values of total coliform and faecal coliform were significantly lower ($p \leq 0.05$) in both filtered and Sûr'Eau treated water than in river water. No statistical differences of means were observed for both total coliform and faecal coliform counts between samples taken from filtered and Sûr'Eau treated water containers (p=0.80 (TC) and p = 0.56 (FC). However, turbidity values were significantly lower in filtered water using SSF than in Sûr'Eau treated water samples (p =0.002). Out of 2814 records form Masaka Health Centre during 2010, 160 cases were identified as having diarrhoeal diseases. Furthermore, respondents who used Nyabarongo River as source of water were more likely to have symptoms of diarrhoea (OR =5.35; CI: 2.12 - 14.46; p <0.05). The frequency of diarrhoea were significantly higher among people who did not wash hands before food preparation (p = 002) and after using a toilet (p = 0.007) than among those who did. There was a statistically significant association of level of education levels and drinking water treatment practices at the household level (p < 0.05). Respondents with primary school education only and those with high school education

were more likely to wash their hands after using a toilet (OR= 5.24, CI 1.42-19.38, p =0.01 and OR = 7.15, CI = 1.79 -28.62, p=0.01, respectively) than those who did not attend school. No significant associations were identified between educational levels and washing hands before food preparation.

The findings of this study points to the facts that water sourced from Nyabarongo River is unsafe for human consumption even after prescribed treatment, such as the use of SSF and Sûr'Eau, and could increase the prevalence of waterborne diseases and therefore calls for urgent provision of potable water. Women in the study areas had limited knowledge regarding water storage practices for prevention of household water contamination and this; underscore the need for more water handling practices and hygiene education in rural communities.

DECLARATION

I, Monique Uwimpuhwe, declare that this is representative of my own work. All sources that I have used or quoted have been indicated and acknowledged by means of complete references. To the best of my knowledge, this work has not been submitted before for any other degree at any other university.

Monique Uwimpuhwe Date

DEDICATION

For Martine, Claire and Emmanuel,

Thanks for your patience, support and love through this journey.

And for everyone who believed in me

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LIST OF ACRONYMS AND ABBREVIATIONS

BSF	BioSand Filter
ANOVA	Analysis of Variance
CDC	Centre for Diseases Control
CI	Confidence interval
DALYs	Disability-Adjusted Life Years
DHS	Demographic and Health Surveys
DRC	Democratic Republic of Congo
DUT	Durban University of Technology
DWAF	Department of Water Affairs and Forestry
EAC	East African Community
EDPRS	Economic Development and Poverty Reduction Strategy
EHEC	Enterohemorrhagic *Escherichia coli*
EIEC	Enteroinvasive *Escherichia coli*
ELECTROGAZ	Public Water and Power Utility
EPEC	Enteropathogenic *Escherichia coli*
ETEC	Enterotoxigenic *Escherichia coli*
FC	Faecal coliforms
FCC	Faecal coliform counts
FRC	Faculty Research Committee
HDR	Human Development Report
HUS	Haemolytic Uremic Syndrome
HWTS	Household water treatment and safe storage
KAP	Knowledge, Attitudes and Practices
KHI	Kigali Health Institute
KWL	Kigali Water Laboratory
MDGs	Millennium Development Goals
MINALOC	Ministry of Local government
MININFRA	Ministry of Infrastructure
MINISANTE	Ministry of Health
MINITERE	Ministry of Lands, Environment, Water and Mines
N	Sample size

NTU	Nephelometric Turbidity Units
NUR	National University of Rwanda
OECD	Organisation for Economic Co-operation and Development
OR	Odds Ratio
ORS	Oral Re-hydration Solution
PAHO	Pan American Health Organization
POU	Point-of-Use
PSI	Population Service International
RBS	Rwanda Bureau of Standards
RR	Relative Risk
RURA	Rwanda Utility Regulatory Agency
RWASCO	Rwanda Water and Sanitation Corporation
SABS	South African Bureau of Standards
SSS	Sugar-Salt Solutions
SODIS	Solar Disinfection system
SWS	Safe water System
TC	Total coliforms
TTC	Thermotolerant coliforms
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency
UV	Ultra-Violet
WHO	World Health Organization
WASH	Water, Sanitation and Hygiene
WSS	Water supply and sanitation
WCC	World Chlorine Council
WSP	Water and Sanitation Program

DEFINITIONS

Cross-sectional study : Cross-sectional surveys are studies aimed at determining the frequency of a particular attribute, such as a specific exposure, disease or any other health-related event, in a defined population at a particular point in time (Bowling, 2001). This study was carried out to estimate the prevalence of waterborne diseases in the study areas in 12 months prior to study.

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Descriptive research : Descriptive research refers to research studies that have as their main objective the accurate portrayal of the characteristics of persons, situations or groups (Polit and Beck, 2004). In this study, the descriptive approach was adopted for collecting data of women's *KAP* regarding waterborne diseases and microbiological water quality at the Nyabarongo River and at the household level.

Guidelines : According to the Oxford Dictionary (2001), guidelines are recommended practices that allow some discretion or leeway in its interpretation, implementation or use. In this study domestic water guidelines were used for interpretation of microbial water quality results.

Indicator bacteria : certain species of bacteria used to assess the microbiological quality of water because although not typically disease causing, they are correlated with the presence of several waterborne disease-causing organisms (Myers, 2003). The term indicator bacteria in this study, used synonymously with fecal indicator bacteria in this study, are a measure of water faecal pollution for consumption.

Knowledge, Attitude and Practice (KAP):

In contemporary research, the term, knowledge, is popularly used in KAP surveys. KAP is a standard term in which the word, knowledge, is implicitly used as a proxy to awareness

(IIDS, 2005). In this study, the terms, knowledge possessed by respondents refer to their understanding of waterborne diseases. Attitude is used to refer to perception or way of thinking and practice to refer to the action or behavior relating to waterborne diseases and water usage.

Prevalence : The total percentage of persons affected by a certain disease in a population (Oxford Dictionary, 2003). In this study, this was used to represent the extent of waterborne diseases in the study areas.

Policy : The set of procedures, rules, and allocation mechanisms that provide the basis for programs and services (Elledge et al., 2002).

Point-of-Use (POU) water treatment:
Refers to a variety of different water treatment methods (physical, chemical and biological) used to improve water quality for an intended use (drinking, bathing, washing, irrigation, etc), at the point of consumption (USEPA, 1997). In this study, POU refers to the household level

Purposive sampling : A deliberately non-random method of sampling which aims to sample a group of people, or settings with a particular characteristic (Bowling, 2001)

Slow sand filtration (SSF) : means a process involving passage of raw water through a bed of sand at low velocity (generally less than 0.4 m/h) resulting in substantial particulate removal by physical and biological mechanisms (USEPA, 1997).

Sûr'Eau : A chlorine-based water treatment product composed of a sodium hypochlorite solution in a plastic bottle with a cap that enables exact dosing for a 20 litre container (USAID, 2008).

Waterborne diseases : Diseases caused by ingestion of water contaminated by human or animal faeces, which contain pathogenic microorganisms (Gray, 2008).

Water quality : A technical term that is based upon the characteristics of water in relation to guideline values of what is suitable for human consumption and for all usual domestic purposes, including personal hygiene (Shelton, 1991). This study evaluated the microbiological aspect of water used in the study households.

CHAPTER 1: INTRODUCTION

1.1 Background to the study

Drinking water quality is an issue for human health in developing and developed countries worldwide. The WHO has stated that every year, 4 billion cases of water related disease cause at least 1.8 million deaths worldwide, making it one of the leading causes of morbidity and mortality. An estimated 99.8% of such deaths occur in developing countries, and 90% are children under the age of five (WHO, 2005; UNICEF, 2008b). In addition, 88% of these diseases are attributed to inadequate water supply, poor sanitation and hygiene (WHO, 2004; Lantagne et al., 2006). Poor quality of drinking water has been implicated in the spread of waterborne diseases such as cholera, dysentery, hepatitis A and E, giardiasis, and Haemolytic Uremic Syndrome (Montgomery and Elimelech, 2007).

These diseases are commonly reported in low-income countries as provision of safe water, sanitation and hygiene is sub-optimal (Rana, 2009). In developing countries, accessibility of safe drinking water is still a problem and people are forced to use available unimproved water sources. These water sources are often microbiologically unsafe and as a result, the most well-known waterborne diseases such as cholera, amoebic dysentery and typhoid are reported from almost all African countries especially in tropical areas of the region including Rwanda (Chabalala and Mamo, 2001, CNN Wire staff, 2010; Onah, 2010; Mugalura, 2010; WASHplus, 2010, WHO, 2010). In Rwanda, diarrhoeal disease is one of the leading causes of child mortality, accounting for an estimated 24 per cent of child deaths (WHO, 2006).

Various pathogenic microorganisms have been suggested as indices of faecal pollution and indicators of microbiological quality of domestic water (Semenza et al., 1998; OECD/WHO, 2003). The most commonly used faecal indicator to determine the microbiological quality of domestic water supplies are the coliform group (total coliform, faecal coliform and *Escherichia coli*) (Meinhardt, 2006; Alotaibi, 2009). Faecal coliforms are an indicator of faecal contamination and are commonly used to evaluate microbiological quality of water and as a parameter to estimate disease risk (Abera et al., 2011).The ratio of faecal coliform to total coliform as bacterial indicators of microbial water quality is based on the premise that coliforms are present in high numbers in the faeces of humans and other warm-blooded animals. Their presence in water samples indicates that faecal pollution has entered drinking water (WHO, 1999; WHO, 2001). Nevertheless, these indicators are not specific and sensitive enough to indicate the presence of certain microorganisms such as enteric protozoa and viruses. Therefore, their absence in water samples provides no guarantee that pathogens such as enteric protozoa and viruses, are also absent (Robertson et al., 2002; Potgieter, 2007). The overall concepts adopted for microbiological quality is that water intended for drinking should contain zero faecal coliform and coliform organisms per 100 ml (WHO, 1997; WHO, 2006).

Lack of access to water supply and sanitation has significant health impacts in rural areas (WHO, 2006). Furthermore, people in rural communities generally lack knowledge on route of waterborne diseases which increases the risk. Many people lack knowledge about potential risks of uncovered and inappropriately stored water, hand washing with soap before eating, preparing food and after defecation (Rana, 2009). The WHO (2007) stated that in addition to providing safe and reliable water services to people who lack access, household level water quality interventions are capable of dramatically improving the microbial quality of household stored water and reducing the risks of diarrhoeal disease and death. In addition, a report prepared for the WHO by Prüss-Üstün et al. (2008), noted that, improving water, sanitation and hygiene has the potential to prevent at least 9.1% of the global disease burden (in disability-adjusted life years or DALYs, a weighted measure of deaths and disability), or 6.3% of all deaths. Interventions to improve microbiological quality of drinking water carried out in developing countries such as Zambia, Bolivia and South Africa reported the effectiveness of household level water treatment techniques such as boiling, sedimentation, filtration, exposure to ultraviolet radiation from sunlight and disinfection with sodium hypochlorite solutions, safe storage and community education (Quick et al., 2002; Sobsey et al., 2003; Potgieter, et al., 2008). Other studies estimate that morbidity levels may be reduced by possibly 6–25% through improved water supply and 32% by improving sanitation, 47% reduction by hand washing with soap and 35% reduction with point-of-use microbial water treatment (Banda et al., 2006). Ultimately, both the source and the household practice determine the levels of contamination and the consumers’ risk for diarrhoeal related illnesses.

1.2 Study location

Rwanda is a small landlocked country, located in the great lakes region of Central East Africa. Its neighbouring countries are Uganda in the North, Tanzania in the East, Burundi in the South and Democratic Republic of the Congo in the West. Rwanda is predominantly a rural country of which 81% of the population are pastoral farmers. It is one of the most densely populated countries in Africa with a population of about 10 million people within 26,338 sq kilometres. The country possesses water in abundance (lakes, rivers and swamps). Surface water covers 211,000 hectares equivalent to 8% of the total national territory, with rivers occupying an area of 7,270 hectares and 22,300 natural springs that feed into rivers and lakes. These rivers meander between hills and ridges scattered all over the country, which is the reason Rwanda is famously known as the "country of a thousand hills". Rwanda is characterized by a temperate climate due to its high elevation; as a result rainwater is abundant. The total annual rainfall varies between 900 and 1,150 mm. However, many rural communities lack proper rainwater collection and storage facilities, and the distribution of drinkable water is still inadequate (Sano, 2007).

According to the national inventory in 2008, access to improved sources of drinking water was estimated at 71% in rural areas of Rwanda. However, 32% of the population use piped water and only 3.4% have access to it within their house or plot. The rest use locally available water sources such as springs, streams and rivers for drinking and other domestic uses. However, many of these water sources serve a large number of villages, and people often have to travel long distances to fetch water. Daily per capita consumption is 6 to 8 litres in rural areas, which is far lower than the standard consumption of 20 litres (World Bank, 2009, MININFRA, 2010).

According to MININFRA (2010), 96% of the population in Rwanda has access to latrines. However, the coverage of adequate sanitation was estimated at 45% in 2009 due to the difficulties to assess individual sanitation as the vast majority of the population use unimproved latrines. This situation contributes to water resource pollution and an increase in water and sanitation related diseases and as a result, almost 80% of all diseases that affect Rwandans are linked to water. Diarrhoea is the second most common cause of death among children under the age of five (UNICEF, 2008b). Rwanda has a high infant mortality rate; 86 deaths per 1,000 live births and approximately 16% of children under the age of five do not survive (Wert and Lee, 2009).

1.3 Kicukiro District

This study was conducted in the Masaka Sector of Kicukiro District which is situated to the South-East of the City of Kigali, the capital of Rwanda (Figure 1.1). Kicukiro is one of the districts facing severe problems linked to lack of access to safe water and adequate sanitation facilities. The hydrograph of the District of Kicukiro is largely constituted of streams and rivers that form part of the Kagera River basin. Figure1.1 shows the location of Masaka in Kicukiro District, Kigali City.

Figure 1.1: Map of Kigali showing the study area (http://www.kigalicity.gov.rw**)**

1.4 Problem statement

Effort has been made by the United Nations (UN) to provide potable water to Africa. One of the millennium development goals is to reduce the number of people without safe drinking water by half by the year 2015 (United Nations, 2007). In addition, Rwanda has a target of providing safe water and sanitation to all Rwandans by 2020 (MININFRA, 2010). However, the country still has a long way to go as many rural areas have insufficient water to meet the most basic drinking and households' needs. Many people have to travel great distances to the water source. This practice consumes a large amount of time particularly for women and children and tends to perpetuate poverty (Berg and Raven, 2006). Despite the abundance of water in Masaka, it is not accessible and people still use untreated water from rivers. They need to travel long distances to get potable water which is further detrimental to health of these women and children. Many other factors affect the microbiological quality of the water, including unhygienic and poorly placed sanitation facilities, population growth and increasing population density which increases the vulnerability to waterborne diseases.

Public taps with potable water in Masaka, function infrequently, forcing residents to use untreated water from the Nyabarongo River. As a result, waterborne diarrhoeal diseases, such as cholera, typhoid, and infectious hepatitis, constitute one of the leading causes of morbidity and mortality in the study areas as well as in the whole country. In 2006, an outbreak of cholera killed 18 people and affected more than 200 others in the Rusheshe and Ayabaraya communities and this outbreak was linked to the use of contaminated water from Nyabarongo River (Weinberger, 2006).

Previous studies conducted in developing countries to improve the microbiological quality of drinking water and reduce waterborne diseases showed the effectiveness of interventions between the source and point-of-use (Sobsey et al., 2005; Lantagne et al., 2006; Potgieter, et al., 2008). Currently, to our knowledge, there are no published studies on the link of microbiological quality of river water, water handling practices and the prevalence of waterborne diseases in rural areas of Rwanda where communities have to use contaminated water as their water sources. A study by Gasana et al. (2002) investigated the impact of water supply and sanitation on diarrhoeal morbidity in young children in Rwanda. The results from this study showed that contaminated water and high open defecation affected young children rendering them more susceptible to diarrhoea.

The present study focused on rural communities (Rusheshe and Ayabaraya) in the Masaka Sector of Kicukiro District in Rwanda. The microbiological quality of raw water and household water after treatment was investigated using total coliform bacteria and faecal coliform bacteria as indictors. This study assessed if the River water is safe for domestic use and if the water treatment methods used at the household level in the study areas are effective for coliform removal in water. This study also determined the prevalence of waterborne diseases in those areas and explored whether educational levels and water handling practices of the women are linked to the occurrence of diarrhoea symptoms in their households. All these parameters are important to assess in order to address issues and problems pertinent to water supply and waterborne diseases in rural areas of Rwanda which could be of interest to many other developing countries. Also, the study intends to inform policy makers, researchers and health practitioners about the constraints that exist in water provision and sanitation in rural Rwanda and possible remedial measures to deal with them.

1.5 Aims and objectives

The aims of this study were to determine the link between the microbiological quality of Nyabarongo River water used by the communities, women's knowledge, attitudes and practices (KAP) on water handling and usage and waterborne diseases and the prevalence of waterborne diseases in Masaka.

The objectives of this study were:

- To measure total coliform and faecal coliform concentration in river water and at the point of use in Masaka.
- To determine the prevalence of waterborne diseases in Masaka in 2010 using retrospective clinic records.
- To assess the knowledge, attitudes and practices regarding water handling and waterborne diseases among women residing in Masaka

This chapter introduced to the study and provided background, rationale and significance as well as the aims and objectives of this study. The following chapter will elaborate on relevant reviewed literature relating to this study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Safe drinking water for human consumption should be free from pathogens such as bacteria, protozoan parasites and viruses and meet the standard guidelines (WHO, 2004). However, lack of access to safe drinking water, together with inadequate sanitation and hygiene are implicated in 88% of diarrhoeal diseases in both developed and developing countries and 2.2 million people die annually of diarrhoea in developing countries (WHO, 2004; Tumwine, 2005). Diarrhoeal diseases are of significant public health importance worldwide and are responsible for 1.8 million deaths every year (WHO, 2005). The United Nations set a goal in their millennium declaration to halve the number of people without safe drinking water by 2015 (United Nations, 2007). More than 1 billion people worldwide lack access to safe water, and an estimated 2.5 billion people do not have access to adequate sanitation facilities (WHO, 2010).

In many developing countries, people living in rural areas collect water from communal sources which are either exposed (e.g. unprotected wells, unprotected springs, and rivers) or improved (e.g. protected wells, boreholes and public standpipes) (WHO/UNICEF, 2000; Sobsey, 2002). The microbiological contamination of water may occur during collection, transport and storage at the point-of-use due to secondary contamination factors (Sobsey, 2002; Gundry et al., 2004). In order to improve water quality and reduce the potential health risk to households, interventions that are functional and sustainable are needed (Sobsey, 2002). Many different water collection and storage systems have been developed and evaluated in the laboratory and under field conditions. In addition, there are a variety of physical and chemical treatment methods that have been developed to improve the microbiological quality of drinking water. Those methods include boiling, heating, filtering, exposing to the UV radiation in sunlight, and UV disinfection with lamps, coagulation-flocculation and precipitation, adsorption, ion exchange and chemical disinfection with germicidal agents (Sobsey, 2002).

2.2 Microbiological quality of drinking water

The term 'water quality' is used to describe the microbiological, physical and chemical properties of water that determine its fitness for use. Many of these properties are controlled or influenced by substances which are either dissolved or suspended in the water. However, microbiological contamination is the most critical risk factor in drinking water quality with the potential for widespread waterborne diseases (Gadgil, 1998; Gray, 2008; Meinhardt, 2006). Water supplies in developing countries are often devoid of treatment and the communities make use of the most convenient supply (Sobsey, 2002). Many of these supplies are unprotected and susceptible to external contamination of surface runoff, windblown debris, human and animal faecal pollution and unsanitary collection methods (WHO, 2000; WHO, 2008).

The microorganisms that cause disease via drinking water are generally known as pathogens and can be categorized in diminishing size as helminths (>100 μm), protozoa (5-100 μm), bacteria (0.5- 1.0 μm) and viruses (0.01-0.1 μm). They originate from either human or animal faeces and if they are not removed by water treatment and disinfection, may cause outbreaks of waterborne diseases (WHO, 2004; Gray, 2008).

2.2.1 Microbial pathogens from faecal contamination

In general terms, the greatest microbial risks are associated with ingestion of water that is contaminated with human or animal faeces. Wastewater discharges in fresh waters and coastal seawaters are the major source of faecal microorganisms, including pathogens (Grabow, 1996; Fenwick, 2006; WHO, 2008). The microbial pathogens of faecal origin that can be transmitted orally by drinking water and which present a serious risk of disease, include *Salmonella spp*, *Shigella spp, enteropathogenic Escherichia coli 0157 (E. coli 0157), Vibrio cholerae (V. cholerae), Yersinia enterocolitica (Y. enterocolitica), Campylobacter jejuni (C. jejuni),* and *Campylobacter coli (C. coli).* Viruses of concern include adenovirus, enterovirus, hepatitis viruses (Gray, 2008).

The most common waterborne pathogens are those that are highly infectious or highly resistant to decay outside the body. Pathogens with a low persistence, i.e. those that do not survive long outside the host, must rapidly find a new host and are more likely to be spread by person-to-person contact or by unhygienic personal or food hygiene than by drinking water (Gray, 2008). While typical waterborne pathogens are able to persist in drinking-water, most do not grow or proliferate in water. Microorganisms (i.e. *E. coli* and *Campylobacter*) can accumulate in sediments and be mobilized with increased water flow or water flow fluctuations. If present in drinking-water, faecal contamination and hence the related waterborne bacterial pathogens are likely to be dispersed widely and rapidly. Outbreaks of waterborne disease are therefore frequently characterised by an infection across an entire community (WHO, 1999; UNICEF, 2008a).

Contamination of drinking water occurs mainly at source although contamination can also occur during treatment or within the distribution system (WHO, 1999). Table 2.1 shows that contamination of otherwise potable water can also occur within the consumer's premises. Bacteria may also enter a water supply through infiltration by flood waters or by surface runoff. Flood waters commonly contain high levels of bacteria. Small depressions filled with flood water provide an excellent breeding ground for bacteria. Whenever a well is inundated by flood waters or surface runoff, bacterial contamination is likely to occur (Oram, 2010). Shallow wells and wells that do not have water-tight casings can be contaminated by bacteria infiltrating with the water through the soil near the well, especially in coarse-textured soils (Oram, 2010).

2.2.2 Type and Use of Indicator Bacteria

Various pathogenic microorganisms have been suggested as indices of faecal pollution and indicators of microbiological quality of domestic water (OECD/WHO, 2003). However, detection of each pathogenic microorganism in water is technically difficult, time consuming and expensive and therefore not used for routine water testing procedures. Instead, indicator bacteria are routinely used to assess the microbiological quality of water and provide an easy, rapid and reliable indication of the microbiological quality of water supplies (WHO, 1999; Potgieter, 2007).

Table 2.1: Routes for faecal contamination of water during collection, transport and storage (UNICEF, 2008b)

Water collection and transport	Water storage
• Use of wide-mouth containers that allow hands to come into contact with water • Use of leaves or other material in buckets to prevent water spillage during transport • Containers are not cleaned • Containers washed with contaminated hands or cloths • Contaminated cups, bowls, ladles or buckets used to draw water	• Use of wide-mouth containers for storage that allow hands, cups/ladles and insect and animal vectors to come into contact with water • Uncovered containers • No spigot or spout on containers – water drawn with cups or ladles • Containers stored on floor, allowing easy access to water by children and animals • Infrequent cleaning of storage containers

A useful indicator of water quality should have the following characteristics (DWAF, 1996; OECD/WHO, 2003):

- Universally present in the faeces of humans and warm-blooded animals in large numbers.
- Should be absent in unpolluted water and present when the source of pathogenic microorganisms of concern is present.
- Should be detectable by practical and reliable methods.
- Should not grow in natural waters and the general environment.
- Should respond to natural environmental conditions and water treatment processes in a manner similar to those of waterborne pathogens.
- Should not be pathogenic and should be safe to work with in the laboratory.

Although many microorganisms have desirable features to be considered as possible indicators of faecal pollution, there is no single indicator organism that meets all these requirements. Therefore, it is better to use a combination of indicator microorganisms in order to obtain the most reliable indication of potential risks of infection (DWAF, 1996; Potgieter, 2007). Based on the above criteria, the recommended indicator bacteria for assessment of the microbiological quality of domestic water include: total coliform, faecal coliform, *E. coli* and faecal enterococci (WHO, 2000). Each of these indicator microorganisms are discussed in more detail in the following sections:

2.2.2.1 Total coliform bacteria (TC)

Different bacterial species that constitute the coliform group may be found in human faeces, animal manure, soil, submerged wood, and at various external locations in the human body (USEPA, 2006). Total coliforms are primarily used as a practical indicator of the general hygienic quality of water; mainly used in routine monitoring of drinking water supplies (DWAF, 1996; WHO, 2000). The recommended test for the enumeration of total coliforms is membrane filtration using mEndo Agar and incubation at 35^{o}C to 37^{o}C for 24 h to produce colonies with a golden green metallic shine.

The presence of total coliforms in water samples indicates the possible presence of opportunistic bacteria such as *Klebsiella* and *Enterobacter* that can multiply in water environments and pathogens such as *Salmonella spp, Shigella spp, V. cholerae, C. jejuni, C. coli, Y. enterocolitica* and pathogenic *E. coli* especially when detected in conjunction with other faecal coliforms.These organisms can cause diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever (DWAF, 1996; OECD/WHO, 2003).

2.2.2.2 Faecal coliform bacteria (FC)

Faecal coliform are Gram negative bacteria also known as thermotolerant coliforms or presumptive *E. coli* (Potgieter, 2007). The faecal coliforms group includes other organisms such as *Klebsiella* spp, *Enterobacter* spp and *Citrobacter spp* which can originate from non-faecal sources and *E. coli* which is specifically of faecal origin from birds, humans and other warm blooded animals. Under most circumstances and especially in temperate areas, the concentration of faecal coliforms is directly related to *E. coli* concentrations (OECD/WHO, 2003). Therefore, detection of thermotolerant coliform in raw water is considered sufficient to determine its faecal contamination and the potential presence of enteric pathogens (Gadgil, 1998; USEPA, 2006). The WHO recommends thermotolerant coliforms as the indicator of choice in assessing the efficiency of water treatment in removing enteric pathogens and faecal bacteria (Gadgil, 1998).

Faecal coliforms are usually enumerated as counts/100 ml by membrane filtration, pour plates or by multiple-tube fermentation techniques. Faecal coliforms produce blue colonies on mFC Agar within 24 h of incubation at 44.5^{o}C (Keyser, 1997). The presence of faecal coliforms in water sample indicates the presence of bacterial pathogens such as *Salmonella* *spp*, *Shigella spp*, *V. cholerae*, *C. coli*, *Y. enterocolitica* and *E. coli* which are implicated in many waterborne diseases. These organisms may cause diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever (DWAF, 1996).

2.2.2.3 Escherichia coli (E. coli)

E. coli are a species of bacteria that is a subgroup of total coliforms and faecal coliform. *E. coli* are generally found in human and warm blooded-animal intestinal tracks, which are used to indicate the recent presence of faecal pollution of water samples (USEPA, 2006). Although *E. coli* are used as an indicator, they have subgroups related to pathogenic strains such as enteropathogenic (EPEC), enteroinvasive (EIEC), enterotoxigenic (ETEC), and enterohemorrhagic (EHEC). The general symptoms of disease caused by these *E. coli* subgroups strains are diarrhoea and bloody diarrhoea, and in the case of enterohemorrhagic strains (e.g., *E. coli* O157:H7), haemolytic uremic syndrome (Anderson and Davidson, 1997). *E. coli* is used to determine the microbiological quality of domestic water supply, since it alone is derived exclusively from the faeces of humans and warm-blooded animals (Meinhardt, 2006; Alotaibi, 2009). Counts of *E. coli* in water are done with the membrane filtration method using mTEC Agar and incubation at 44.5^{o}C for 24 h. *E. coli* produce yellow, yellow-green or yellow-brown colonies on a filter pad. The presence of *E. coli* in water indicates not only recent faecal contamination of the water but also the possible presence of intestinal disease causing bacteria, viruses, and protozoa (WHO, 2006).

2.2.2.4 Faecal Enterococci

Faecal Enterococci bacteria include species known to cause human infection such as *Enterococcus faecalis, Enterococcus faecium, Enterococcus avium, Enterococcus gallinarum and Enterococcus durans* (WHO, 1996). *Enterococci* are spherical, Gram positive bacteria which are highly specific for human and animal faecal pollution (OECD/WHO, 2003). The recommended test is membrane filtration using m-Enterococcus agar after 48 hours incubation at 35^{o} C to 37^{o}C to produce pink colonies. These bacteria often appear in human and animal faeces, but in lower numbers than total or faecal coliforms and are more resistant than *E. coli* and other coliform bacteria. The presence of *Enterococci* in water samples indicates the increased risk of more specific diseases such as meningitis, endocarditis and infection of the eyes, ears and skin (DWAF, 1996; Potgieter, 2007).

The most commonly used faecal indicator bacteria to determine the microbiological quality of domestic water supplies is the coliform group (Meinhardt, 2006; Alotaibi, 2009). The United States Environmental Protection Agency (USEPA) recommends that total coliforms be used as indicators for drinking water supply because the presence of total coliform reveals intrusion of contaminants from the environment into the water supply system (USEPA, 2006). The ratio of faecal coliform to total coliform as bacterial indicators of microbial water quality is based on the premise that coliforms are present in high numbers in the faeces of humans and other warm-blooded animals. If faecal pollution has entered drinking water, it is likely that these bacteria will be present, even after significant dilution (WHO, 1996; WHO, 2001). Nevertheless, because coliform bacteria are very sensitive to chlorine, their absence provides no guarantee that pathogens such as enteric protozoa and viruses, which are resistant to chlorine, are also absent (Robertson et al., 2002). Another disadvantage is that some faecal coliforms and total coliforms can multiply in the environment (soil and water) (Potgieter, 2007).With a few exceptions, coliforms themselves are not considered to be a health risk, but their presence indicates that recent faecal pollution may have occurred and pathogens might be present as a result (WHO, 1996; WHO, 2001).

2.2.3 Turbidity of water

Turbidity is a measure of the cloudiness of water and is indicative of the concentration of suspended matter in water. Turbidity in water is caused by the presence of suspended matter which usually consists of a mixture of inorganic matter, such as clay and soil particles, and organic matter and therefore reflects increases or decreases in biofilm formation. However, it may be both living matter such as micro-organisms and non-living matter such as dead algal cells. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are present) (USEPA, 2002). Turbidity is measured in Nephelometric Turbidity Units (NTUs) which refers to the type of instrument (turbidimeter or nephelometer) used for estimating light scattering from suspended particulate material. Turbidity is most often used to estimate the (total suspended solids (TSS) as [mg dry weight]/l) (USEPA, 2002). Levels of turbidity in raw water can range from less than 1NTU to more than 1,000 NTU. Ideally, median turbidity in drinking water samples should be below 1 NTU. Consumers usually accept the appearance of water with turbidity less than 5 NTU (WHO, 2004).

The presence of microorganisms is often associated with increased turbidity; hence low turbidity reduces the potential for transmission of infectious diseases (DWAF, 1996). Atherholt et al. (1998) and Medema et al., (2003) showed in river water monitoring study that the concentration of *Cryptosporidium* spp and of faecal indicator bacteria was positively correlated with turbidity. Another study carried out in Iran (Sadeghi et al., 2007) indicated that was a significant relationship ($p<0.023$) between the turbidity and microbiological quality of water. Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhoea, and associated headaches (DWAF, 1996; USEPA, 2002).

2.2.4 Microbiological drinking water guidelines

Bacterial guidelines for drinking water are critical because they regulate water that directly affects human health and represents life time exposure. It is thus imperative to ensure safe and bacteria-free drinking water (WHO, 2006). Drinking water becomes contaminated when faeces containing pathogens are deposited or flushed into the water. If treatment is insufficient, or if the water distribution system is inadequate, drinking water may contain sufficient numbers of pathogens to cause illness (O'Connor, 2002).

In general, every country has its own set of guidelines for drinking water. However, most of these guidelines are similar for different countries, and the same indicator microorganisms are used. WHO (1999, 2006) recommends that *E. Coli* or thermotolerant coliform and total coliform bacteria should not be detected in any 100 ml sample of water intended for drinking. According to East African water guidelines, including Rwandan guidelines, potable water should contain zero *E. coli* per 100 ml of water and zero total coliform bacteria per 100 ml of water (RBS, 2010).

Rwanda Utilities Regulatory Agency (RURA) (2009) states that water tests should be performed continually to ensure that water is within required standards as specified by the WHO and Rwandan guidelines and that 99% of water samples should meet the standards. However, 100% should meet standards for pathogens. Both WHO and Rwanda Bureau of Standards (RBS) recommend regular sampling of treated water supplies, and that not more than 5% of the samples in any 12-month period should test positive for total coliforms, *E. coli* or thermotolerant coliforms. WHO recognizes that these targets would be difficult to achieve in some cases, especially in rural communities with untreated water supplies, and recommends that in these settings, the guidelines values should be seen as goals for the future, rather than an immediate requirement (UNICEF, 2008a). In fact, the World Bank says that in most developing countries the imperative is to get from poor quality (more than 1,000 faecal coliforms per 100 ml) to acceptable quality (less than 10 faecal coliforms per 100 ml) do not necessarily meet the stringent quality standards of industrial countries (Gadgil, 1998).

In addition, in South Africa the guidelines for water quality (SABS, 2001), specifies three classes of water in terms of microbiological quality. The risk of being infected by microbial pathogens correlates with the level of contamination of the water and the amount of contaminated water consumed. The ideal situation for faecal coliforms is where drinking water is suitable for consumption is when at least 95% of samples have no detected faecal coliforms. Counts ranging between 10 and 20 counts per 100 ml in water samples are considered of a slight risk of infectious disease transmission, whereas greater than 20 per 100 ml of water suggests a significant and increased risk of infectious disease transmission. A similar rule exists for total coliforms, except that 10 and 100 counts per 100 ml are considered as of a slight risk of infectious disease transmission at the 4% and 1% levels. In spite of this, the goal of disinfection should be to attain 100% compliance with no detected bacteria (DWAF, 2005).

2.3 Waterborne diseases

Waterborne diseases are associated with water contaminated by human or animal faeces containing pathogens and are a major cause of morbidity and mortality worldwide (UNICEF, 2008a). Waterborne diseases are caused by enteric pathogenic organisms such as bacteria, viruses and protozoa, which may cause diseases cholera, dysentery, typhoid fever, hepatitis A and E, giardiasis and schistosomiasis (Table 2.2) (Montgomery and Elimelech, 2007; UNICEF, 2008a).

Waterborne spread of infection by pathogenic microorganisms depends on several factors such as: the survival of these microorganisms in the water environment, the infection dose of the microorganisms required to cause a disease in susceptible individuals, the microbiological and physico-chemical quality of the water, the presence or absence of water treatment and the season (Lecrerc et al., 2001**;** Potgieter, 2007). The survival of microorganisms in water environments depends on the presence of nutrients and the water temperature.

Table 2.2: Waterborne diseases and their symptoms (UNICEF, 2008a; Viessman et al., 2009; Gray, 2008; USEPA, 2009; Cabral, 2010)

Disease	**Microbial Agent**	**Disease Symptoms**
	Bacteria	
Gastroenteritis	*Campylobacter species*	Fever, abdominal pain, diarrhoea
Bacillary dysentery	*Shigella species*	Fever, diarrhoea, bloody stool
Cholera	*Vibrio cholerae*	Severe Watery diarrhoea, vomiting, occasional muscle cramps
Typhoid fever	*Salmonella typhi*	Fever, headache, constipation, appetite loss, nausea, diarrhoea, vomiting, appearance of an abdominal rash
Salmonellosis (oral transmission)	*Salmonella* species	Gastroenteritis, fever and rapid blood-poisoning.
Haemolytic uremic syndrome	*E. coli* O157:H7	Bloody diarrhoea and stomach pain
	Protozoa	
Cryptosporidiosis	*Cryptosporidium parvum*	Diarrhoea, abdominal discomfort
Giardiasis	*Giardia lamblia*	Diarrhoea, abdominal discomfort
Amoebiasis	*Entamoeba histolytica*	Abdominal discomfort, fatigue, diarrhoea, flatulence, weight loss
	Parasites	
Taeniasis	Tapeworms of the genus*Taenia*	Intestinal disturbances,neurologic manifestations, loss of weight, cysticercosis
Fasciolopsiasis	*Fasciolopsis buski*	GIT disturbance, diarrhoea, liver enlargement, cholangitis,cholecystitis, obstructive jaundice.
Ascariasis	*Ascaris lumbricoides*	Mostly, disease is asymptomatic or accompanied by inflammation, fever, and diarrhoea. Severe cases involve Löffler's syndrome in lungs, nausea, vomiting, malnutrition, and underdevelopment.
Toxoplasmosis	*Toxoplasma gondii*	"Flu" with swollen lymph glands or muscle aches, damage to the brain, eyes, or other organs
	Viruses	
Infectious hepatitis	Hepatitis A	Fever, chills, abdominal discomfort, jaundice, dark urine
Viral Gastroenteritis	Norwalk, rotavirus and other types of viruses	Fever, headache, gastrointestinal discomfort, vomiting, diarrhoea
Toxoplasmosis	*Toxoplasma gondii*	"Flu" with swollen lymph glands or muscle aches, damage to the brain, eyes, or other organs

The infectious dose of some bacteria ranges between 10^7 and 10^8, with some enteric bacteria able to cause infections at doses as low as 10^1 cells (Gadgil, 1998; Mara and Horan, 2003). Viruses cannot replicate outside living cells but can survive for extended periods in water.
The infectious dose of viruses has been established as low as 1 to 10 infectious particles. Enteric protozoa such *Giardia* and *Cryptosporidium* cannot replicate in water and are highly resistant to most disinfectants and antiseptics used for water treatment. The infectious dose for parasites depends on host susceptibility and strain virulence. The infectious dose of *Giardia* ranges between 10 and 100 cysts and for *Cryptosporidium* the presence of 10 oocysts might cause an infection (Yates, 2006; Potgieter, 2007). The minimum infectious dose also varies by the age, health, nutritional and immunological status of the exposed individual. As WHO notes, those at greatest risk of waterborne disease are infants and young children, people who are debilitated or living under unsanitary conditions, the sick and the elderly (Gadgil, 1998).

The most common manifestation of waterborne illness is gastrointestinal upset (nausea, vomiting, and diarrhoea), and this is usually of short duration (WHO, 2006); However, in susceptible individuals such as infants, the elderly, and immune compromised individuals, the effects may be more severe and cause harmful effects (e.g., kidney damage) (Cairncoss and Feachem, 1996). Table 2.2 lists some of the main pathogens of concern in drinking water, disease caused and symptoms. Most of these pathogens can be found in faecal matter from infected humans and many may also be present in animal faeces.

Two of the waterborne diseases, cholera and dysentery, are particularly infectious and can cause severe epidemics (UNICEF, 2008a). These diseases will be discussed in detail in the following sections.

2.3.1 Cholera

Cholera is an acute infectious disease caused by a bacterium *Vibrio cholerae* (*V. cholerae*), which can infect humans mainly via water or food contaminated with faeces. However, Cholera outbreaks are often associated with unsafe water supplies and inadequate hygiene (Cabral, 2010). *V. cholerae* is a Gram negative bacterium which can grow at 40^{o}C at pH 9-10. *V. cholerae* survive in the cultivable state in water, aquatic and marine organisms for a considerable period of time (Wallace, 2008). They are very common in seas, rivers and estuarine associated with blue-green algae, living free or on the surfaces and in the intestinal contents of marine animals (Farmer et al., 2005). The infectious dose is very large, at least 10^6 organisms, under normal circumstances due to the sensitivity of *V. cholerae* to low pH environments (Mara and Horan, 2003).

When *V. cholerae* face adverse environmental conditions, they reduce cell size, become coccoid and enter a dormant stage inside exopolysaccharide biofilms. Cells display a certain metabolism, but are not able to grow in vitro. Cells in this viable but non-culturable state retain viability as well as the potential for pathogenicity for significant periods of time (Mara and Horan, 2003).Viable but non-culturable cells can leave their dormant stage and multiply again, resulting in an explosion of their concentration in the environment. Since the presence of non-toxigenic strains is common in aquatic milieu, especially in estuaries, if a horizontal transfer of cholera exotoxin producing genes occurs between toxigenic and non-toxigenic strains, the number of toxigenic cells in the environment can rise rapidly and pronouncedly. The episodic nature and the sudden appearance of violent cholera outbreaks, followed by a rapid slowing down, are probably related to these phenomena (Cabral, 2010).

The incubation period for cholera is 1 to 3 days (Mara and Horan, 2003). The disease is characterized by acute and intense diarrhoea. Cholera symptoms include thirst, muscular pains, general weakness, and signs of oliguria, hypovolemia, hemoconcentration, followed by anuria. Patients feel lethargic and blood potassium drops to very low levels. Finally, circulatory collapse and dehydration with cyanosis occurs (Wallace, 2008). Lower socioeconomic groups have a higher incidence of cholera for a variety of reasons including occupational exposure, unsanitary conditions in low-income housing areas, primarily reflected in inadequate sewage disposal and contaminated water sources and high population density, increasing the risk of introduction of *V. cholerae* and possibly enhancing the growth of organism after it has been introduced (Wallace, 2008).In the absence of treatment, the disease has a 60% death-rate, the patient dying within few hours of first showing symptoms, although with suitable treatment the death-rate can be reduced to less than 1% (Gray, 2008). Cholera remains a global threat and is one of the key indicators of social development. While the disease no longer poses a threat to countries with minimum standards of hygiene, it remains a challenge to countries where access to safe drinking water and adequate sanitation cannot be guaranteed (WHO, 2011).

2.3.2 Bacillary dysentery (Shigellosis)

Bacillary dysentery, most easily defined as bloody diarrhoea, is an infectious disease of the intestinal tract caused by bacteria of the genus *Shigella*. The genus *Shigella* is spread through water or food contaminated by faeces. *Shigella* infection is typically via ingestion (faeco–oral contamination); depending on age and condition of the host, as few as 10 to 200 bacterial organisms can be enough to cause an infection (Wallace, 2008). The usual incubation period of shigellosis ranges from less than 12 hours to 6 days (Wallace, 2008). Dysentery is characterized by abdominal pain, diarrhoea with bloody mucous stool which is moved several times with a small amount each time, tenemus, burning sensation at the anus, scanty dark urine, chill and fever, yellow and greasy coating of the tongue and rapid pulse rates (Mara and Horan, 2003; Cabral, 2010).

Dysentery is initially managed by oral rehydration therapy. If this treatment cannot be adequately maintained, hospital admission may be required for intravenous fluid replacement. It can usually be treated with antibiotics, such as ampicillin, trimethoprim/sulfamethoxazole (also known as Bactrim or Septra), nalidixic acid and the fluoroquinolone, ciprofloxacin. *Shigella* infections are less common in communities with access to potable water and good sanitation. Hand washing practices have proven to be an effective control measure even in area with poor sanitation (Wallace, 2008).

2.3.3 Pathogenic *Escherichia coli* strains

E. coli strains isolated from intestinal diseases have been grouped into at least six different main groups. From these, enterohemorrhagic (EHEC, namely O157) is of importance and can be transmitted through contaminated water (Cabral, 2010).*E. coli* 0157:H7 is a Gram negative bacillus that is part of the normal intestinal flora of humans or animals. *E. coli* 0157:H7 may produce bloody diarrhoea due to toxins it secretes when it infects human intestinal tracts. The initial symptoms of *E. coli* O157:H7 infection usually appears about 3 to 5 days after a person ingests the bacteria. The symptoms may include a low fever, nausea, vomiting, severe abdominal cramps, and bloody diarrhoea (Wallace, 2008). *E. coli* 0157:H7 may cause additional complications in children and the elderly; renal failure, anaemia, and dehydration especially for children (termed HUS or Haemolytic-uremic syndrome) and spontaneous bleeding, organ failures, and mental changes in the elderly. Patients, especially healthy adults, often require no treatment for *E. coli* O157:H7 since many infections are self–

limited. Moreover, for the acute diarrhoeal illness, antibiotics have not proven useful. In fact there is evidence that suggest that antibiotic therapy increases the risk for the subsequent development of HUS. When necessary, treatment includes the replacement of fluids and electrolytes to treat or prevent dehydration (Hunter, 1999; Wallace, 2008).

2.3.4 The global burden of waterborne diseases

Exposure to contaminated water contributes significantly to waterborne diseases especially diarrhoeal diseases worldwide. The WHO (2005) estimates that approximately 4 billion cases of diarrhoea each year cause at least 1.8 million deaths, 90% of which are children under the age of five. Eighty-eight percent (88%) of these deaths are attributable to the use of either untreated or inadequately treated ground surface waters, inadequate sanitation and poor hygiene (WHO, 2005; UNICEF, 2008b). Waterborne diseases are distributed worldwide; however, the burden is high in developing countries where a large part of the population does not have access to safe drinking water (WHO, 2003).

Drinking water-related outbreaks of pathogenic *E. coli* have been reported as early as 1965 (in Sweden) and 1971 (in the United States). Since then, drinking water-related outbreaks of pathogenic *E. coli* have occurred throughout the world (Cabral, 2010). There were 27,000 reported outbreaks of *Campylobacter enteritis* in the UK during 1987, rising to over 30,000 in 1990 causing acute diarrhoea and it is now thought that *Campylobacter* is the major cause of gastroenteritis in Europe, making it more of a threat than *Salmonella* (Gray, 2008). A *Cryptosporidium* outbreak in Georgia in 1987 affected 13,000 people. The most important outbreak of Cryptosporidiosis occurred in the USA during April 1993 where 440,000 people became infected and of the 4,400 that were hospitalized, 50 people died, making *Cryptosporidium* the most serious waterborne disease in developed countries (Gray, 2008).

In sub-Saharan Africa, diarrhoeal diseases are a leading cause of death in children under the age of five. It is estimated that each child has five episodes of diarrhoea per year and that 800,000 of those children will die from diarrhoea and associated dehydration. Since 1991, dysentery epidemics have occurred in eight countries in Africa (Angola, Burundi, Malawi, Mozambique, Rwanda, Tanzania, Democratic Republic of Congo (DRC) and Zambia) (Chabalala and Mamo 2001).

Over the past 20 years, trends of cholera have shifted from a high incidence in the Americas during the early 1990s towards high incidence in Africa today, with a few cases reported from Asia. Globally, cholera incidence has increased steadily since the beginning of the millennium. Cholera outbreaks persist in Sub-Saharan Africa, and this disease continues to pose a public health problem among developing world populations without access to adequate water and sanitation resources. In 2007, various countries around the world reported 178,677 cases of cholera and 4033 cholera deaths to the WHO. About 62% of those cases and 56.7% of deaths were reported from the WHO African Region alone (Cabral, 2010). In 2009, a total of 45 countries from all continents reported 221,226 cases of cholera to the WHO, of which 98% were reported from Africa (WHO, 2011). Recent cholera and other diarrhoeal diseases outbreaks reported from developing countries: Cameroon, Nigeria, Tanzania, Zimbabwe, Somalia and South Africa were attributed to contaminated drinking water and inadequate sanitation (CNN Wire staff, 2010; Onah, 2010; Mugalura, 2010; WASHplus, 2010, WHO, 2010). Recently a total of 3,896 cholera cases, including 265 deaths have been reported in Congo and these cases were associated with the use of water from the Congo River (WHO, 2011).

In rural communities of South Africa, severe outbreaks of cholera have been reported during 2000 to 2004, with confirmed deaths in KwaZulu-Natal, Limpopo, Eastern Cape and Mpumalanga (DOH, 2000; DOH, 2002; DOH, 2003; Potgieter, 2007). In 2009, 2000 cases of cholera were recorded with 15 cases of mortality across the country and mostly in Limpopo province (DOH, 2009). In addition typhoid cases have been reported in Limpopo and Mpumalanga provinces during 2004 and 2005 with cases of mortality (Potgieter, 2007).

In 1994, after the influx of 800,000 Rwandan refugees into North Kivu, DRC, 85% of the 50,000 deaths were caused by diarrhoeal diseases, of which 60% were a result of cholera and 40% were caused by Shigella dysentery. In 2006, an outbreak of cholera in Rwanda killed 18 people and affected more than 200 others in rural communities of Masaka (Weinberger, 2006). In 2009, 25 cases of cholera were reported in the north-western region of the country. These outbreaks were linked to the use of contaminated water from local rivers (TRAC, 2009). These statistics show a need for the implementation of a national surveillance and reporting system to monitor waterborne diseases.

2.4 Source water supply

In many developing countries, potable water is collected from communal sources which are either exposed (e.g. unprotected wells, unprotected springs, and rivers) or improved (e.g. protected wells, boreholes and public standpipes) (WHO/UNICEF, 2000; Sobsey, 2002). The primary source of human pathogens in water sources has been from human waste. Animal waste also carries pathogens that affect people as well as other animals. Discharge of domestic wastes into surface waters allows pathogenic bacteria to be dispersed downstream (Goel, et al., 2004).

Several studies carried out in developing countries investigated the microbiological quality of these improved and unimproved water sources and the results obtained were different depending on the water source. The results of a study carried out in Saudi Arabia, indicated that water collected from traditional sources (wells) showed increases in most of the investigated bacteriological parameters, followed by surface water and bottled or desalinated water. Coliforms were not detected in any samples taken from bottled water, but it was detected in samples taken from desalinated, surface, and well water; of 12.9%, 80%, and 100%, respectively (Alotaibi, 2009). Faecal coliforms were detected in desalinated, surface, and well water, of 3.23%, 60.0% and 87.88%, respectively (Sobsey et al., 2003; Gaundry et al., 2004; Prasai et al., 2007; Alotaibi, 2009).

It has been shown that river water used for domestic purposes by rural Indian communities was contaminated by enteric pathogens (Goel, et al., 2004). A study to evaluate the quality of water supply in Venda by Potgieter *et al*. (2000) showed that river water exceeded recommended quality guidelines for water intended for domestic purposes. The results lock indicated that faecal coliforms present in the river water were in the range of 100 to 1,000 cfu/100 ml and occasionally as high as 80,000 cfu /100 ml. Another study by Bessong et al. (2009) carried out in a rural community of South Africa showed that indicator microbial counts for total coliforms, faecal coliforms, enterococci, and heterotrophic bacteria exceeded the limit for no risk as stipulated by the South African water-quality guidelines for domestic use for the Khandanama River.

Kravitz et al. (1999) demonstrated, in their study carried out in Lesotho Highlands, Southern Africa, that based on the estimation of total coliform which is a nonspecific bacterial indicator of water quality, all unimproved and semi-improved water sources were to be considered as not potable. *E. coli*, a more precise indicator of faecal pollution was absent in improved water sources ($P<0.001$). The study suggests that protection of water sources can improve the microbiological quality of rural water supplies, where disinfection is not feasible. Sobsey (2002) described various interventions strategies to improve the water quality at the source. These improvements can include the building of reservoirs, building protective structures around boreholes and fountains, providing communities with communal taps closer to the dwelling and the treatment of the water source with a disinfectant. In Rwanda, to our knowledge, there is no published study to determine the microbiological quality of water sources used by rural communities.

2.5 Point- of- use water management in the households

Household-level approaches to drinking water treatment and safe storage are also commonly referred to as managing water at the "point-of-use" (POU) (WHO, 2007). POU drinking water treatment and safe storage options can reduce risks of disease until the longer-term goal of universal access to piped, treated water is achieved. By preventing disease, household water treatment and storage practices can contribute to poverty alleviation and development (UNICEF, 2008b). Their widespread use, in conjunction with hygiene education and latrine provision, has the potential to save millions of lives until the infrastructure to reliably deliver safe water to the greater population has been created. Household water treatment and safe storage (HWTS) interventions can lead to dramatic improvements in drinking water quality and reductions in diarrhoeal disease making an immediate difference to the lives of those who rely on water from polluted rivers, lakes and, in some cases, unsafe wells or piped water supplies (UNICEF, 2008b; WHO, 2010)

Various studies have reported deterioration of microbiological quality of the water after collection during transport and storage at the point-of-use in the households. A review on contamination of drinking water between source and point-of-use in rural households of developing countries, published by Gundry et al. (2004), indicated that water from the household storage was more contaminated than water from the water source. The results showed that 12% of source samples were contaminated while, in household storage, more than 40% of samples were contaminated. The review found that samples of stored water contaminated with *V. cholerae* resulted in cholera cases and that treatment and improved storage interventions were successful at preventing cholera.

2.5.1 Water collection from the source water supply

In most developing countries the task of collecting water falls to women. In rural Africa women often walk ten miles or more every day to fetch water (Sobsey, 2002). The work involved in fetching may differ in each region, it may vary according to the specific season, and it depends on the time spent on the queue at the source, the distance of the house from the source and the number of household members for which water must be collected. Water for domestic use may be collected either by dipping the container inside the water supply, collecting rainwater from a roof catchment system or by collection using different types of pumps (Potgieter, 2007).

Various water collection vessels are used in developing countries including locally available buckets, pots, urns, jerry cans, barrels; used beverage containers and flexible bags and flagons are usually low in cost and readily available. However, only some of these, in particular jerry cans, some plastic beverage containers, some urns and some flexible vessels, have properties and characteristics that are preferred or desirable as water storage vessels. Others, such as some buckets, cooking pots, some plastic beverage containers and other cylindrical vessels are less desirable for household water storage, but may be suitable for water collection and transport, especially if they are lightweight, have protective lids and are composed of easily cleaned materials (e.g., plastics) (Sobsey, 2002).

2.5.2 Household water storage

Due to distances and unavailability of piped water to dwellings or inside the households in many rural communities, people are forced to store their drinking water (Potgieter, 2007). However, storing water can provide a number of opportunities for microbiological contamination. Transmission of microorganisms in the household can occur through several routes. The most important transmission routes include water, food, and person-to person contact, unhygienic behaviour, storage conditions at the POU and decantation conditions of water from the storage container (Roberts et al., 2001; Potgieter, 2007). In rural households water storage containers are often not cleaned and exposed to faecal contamination due to children who put their hands into the water, unhygienic handling of the water storage containers, and the use of dirty utensils to withdraw water, dust, animals, birds and various types of insects (Sobsey, 2002; CDC, 2009).

In addition, studies have indicated poor storage conditions and inadequate water storage containers as factors contributing to increased microbial contamination compared to either source waters or water stored in improved vessels. Higher levels of microbial contamination and decreased microbial quality were associated with storage vessels having wide openings (e.g., buckets and pots), vulnerability to introduction of hands, cups and dippers that can carry faecal contamination, and lack of a narrow opening for dispensing water (Sobsey, 2002; Seino et al., 2007). Notably, a study by Quick et al. (2002) indicated that there was a significant reduction in diarrhoeal and other waterborne diseases in the community after disinfection and safe storage of drinking water at the point of consumption ($p < 0.001$; OR: 0.52, 95% CI: 0.3, 0.9). Stored water in intervention households was significantly less contaminated than water in control households.

The United States Centre for Diseases Control (CDC) and the Pan American Health Organization (PAHO) have described the characteristics of the most preferable containers used by rural households for drinking water storage (Potgieter, 2007).Those containers include containers with narrow openings for filling, and dispensing devices such as spouts or taps/spigots. Many container designs also have handles, are lightweight, are from durable UV-resistant plastic and are affixed with a label containing informational/educational on their cleaning and use. Other appropriate containers for safe storage are those in which water can be directly treated by the physical method of solar radiation and then directly stored and dispensed for household use. These improved containers protect stored household water from the introduction of microbial contaminants via contact with hands, dippers, other faecally contaminated vehicles or the intrusion of vectors (CDC, 2009; WHO, 2011).
Based on these characteristics, the CDC has designed a 20 l container, a modified jerry can, to decrease the risk of contamination. Together with the use of a sodium hypochlorite solution, this container has been proved effective in several studies carried out in developing countries in Africa, Europe and South America (Potgieter, 2007; CDC, 2009). Other containers designed to provide safe water storage as by CDC (2009) include the 14 l Oxfam Bucket and modified Clay Pots. The lids snap on to prevent entry of the hands or objects into

the container. These storage containers need to be covered at all times to prevent flies and small children from touching the water (Sobsey, 2002).

Additionally, Clasen and Bastable (2003) noted that intervention studies that employed a three part intervention program involving narrow mouth storage containers with spigots that prevent hands from entering container; point-of-use disinfection; and community hygiene education have led to reductions in waterborne disease incidence, as was evident by a 50% reduction in diarrhoea incidence in Bangladesh (Sobsey et al., 2003), 44% and 50% in Bolivia (Quick et al., 2002; Sobsey et al., 2003, respectively) and 62% in Uzbekistan (Semenza et al., 1998). An intervention study using a narrow-neck clay container found that cholera carrier rates were 17.3% in the control group and 4.4% in the intervention group (Deb et al., 1986). These results indicate that the type of storage container and whether the container allowed contact of hands with the stored water were associated with increased diarrhoeal disease incidence (Schafer, 2010).

The material of the storage container is also important because the chemical material of the storage container may be conducive to bacterial growth and survival of potentially pathogenic microorganisms if contamination of water occurs (Potgieter, 2007). CDC (2009) stated that it is preferable, especially when using treatment options that do not leave residual protection, to store treated water in plastic, ceramic, or metal containers. Copeland et al. (2009), in their study in Brazil, showed that the type of storage material had a significant effect on the susceptibility to contamination ($\chi^2 = 12.090$; $p = 0.007$). Water samples were three times more likely to be contaminated during storage in a filtered clay pot than in a bottle (27.3 versus 9.3%). Additionally, a laboratory study found that factors such as long retention times of 4 to 7 days, low or no chlorine residual and temperatures above 15°C, increase microbial re-growth in 1000 L fiberglass, polyethylene and cast iron household storage tanks as measured by *E. coli* counts ($p = 0.082$) (Schafer, 2010).

Other factors contributing to greater risks of microbial contamination of stored water at the point-of-use include, higher temperatures, increased storage times, higher levels of airborne particulates, inadequate hand washing and the use of stored water to prepare food that become microbiologically contaminated and contribute to increased infectious disease risks (Sobsey, 2002; Potgieter, 2007). In addition, inadequate cleaning measures of the storage containers could lead to the formation of biofilms, which may harbour potentially pathogenic and opportunistic microorganisms. These microorganisms could survive longer than 48 hours in biofilms inside household drinking water storage containers and pose a potential risk factor for humans consuming this water (Sobsey, 2002; Potgieter, 2007).

2.5.3 Household level water treatment

Household treatment is an option increasingly adopted by householders themselves. Properly protected water sources, well managed municipal and community treatment systems should result in safe water for consumers. However, this is often hard to achieve, especially in rural and poor urban areas in developing countries. Leaky and sporadically functioning distribution systems allow recontamination to occur, as do poor hygiene, water transport and storage practices. In some cases, in many developing countries, safe water is simply not available and people rely on contaminated water sources, where the only alternative is to treat water in the home (UNICEF, 2008b).

Numerous studies have shown that improving the microbiological quality of household water by on-site or point-of-use treatment and safe storage in improved vessels reduces diarrhoeal and other waterborne diseases in communities and households of developing as well as developed countries. Reductions in household diarrhoeal diseases of 6-90% have been observed, depending on the technology and the exposed population and local conditions (Sobsey, 2002; Montgomery and Elimelech, 2007).

Several technologies to improve the microbial quality of household water and reduce waterborne disease have been developed and include a number of physical and chemical treatment methods (Sobsey, 2002; WHO, 2007). The physical methods, include boiling, heating (fuel and solar), settling, filtering, exposing to the UV radiation in sunlight, and UV disinfection with lamps. The chemical methods include coagulation-flocculation and precipitation, adsorption, ion exchange and chemical disinfection with germicidal agents (primarily chlorine). However, many of these treatments are not suitable for conditions in rural communities (Sobsey, 2002; Lantagne et al., 2006; Potgieter, 2007).

Of the above household water treatment and storage interventions, boiling, sedimentation, solar disinfection, filtration, chlorination, and the combined treatments of chemical coagulation-filtration have been proven to improve microbiological quality by reducing bacteria, viruses and in some cases protozoa in water samples in developing countries (Lantagne et al., 2006; WHO, 2010). The advantages and disadvantages with regards to the use of these household treatments methods used in developing countries are discussed in the following sections.

Boiling water is widely used since it is easy and is highly effective at removing pathogens. A study carried out in rural Guatemala by Rosa et al. (2010) indicated that boiling significantly improved the microbiological quality of drinking water. The results showed that boiling water was associated with 86.2% reduction in mean thermotolerant coliforms (TTC) (N = 206, $P < 0.0001$). However, due to rising fuel costs and disappearing forests, this is increasingly out of reach for most people (Potgieter, 2007; UNICEF, 2008b). A further concern is that water is often transferred to storage container for cooling and thus can become re-contaminated (Sobsey, 2002).

Plain Sedimentation or Settling is used for very turbid water. The quality of water sometimes can be improved by holding or storing it undisturbed and without mixing long enough for larger particles together with large microbes to settle out by gravity. The settled water can then be carefully removed and recovered by decanting, ladling or other gentle methods that do not disturb the sedimented particles. Sedimentation often is effective in reducing water turbidity. The disadvantage of sedimentation is that fine clays and pathogenic microorganisms such as viruses and bacteria do not settle (Sobsey, 2002).

Natural solar disinfection (SODIS): When small transparent bottles of water are left out in the sun for a period of time, the combined effect of ultraviolet radiation (UV-A) and heat inactivates most pathogens, making the water safe to drink (Lantagne et al., 2006). SODIS is widely used because it is ultra-low cost or free (using discarded plastic bottles) and relatively simple to implement. However, because at least 6 hours of exposure to bright sunlight is required to de-activate pathogens, SODIS is not applicable in some climates and during rainy seasons. The technique also requires low-turbidity water to be effective (Lantagne et al., 2006; UNICEF, 2008b). In addition, previous studies provided limited evidence for its effectiveness in reducing diarrhoea. A recent study carried out in rural Bolivia (Mäusezahl et al., 2010) found no strong evidence for a substantive reduction in diarrhoea among children (the Relative Risk (RR) = 0.81, 95% CI 0.59–1.12).

Filtration is a widely used method that removes particles and some microorganisms from water (Potgieter, 2007). A variety of filter media and filtration processes are available for household or point-of-use treatment of water. However, the removal of microorganisms, the cost and availability of the filtration media and methods in developing countries vary widely and often depend on local factors (Sobsey, 2002). Filtration through porous granular media, typically sand or successive layers of anthracite coal and sand, is the most widely used physical method for water treatment at the community level, and it has been used extensively for on-site treatment of both community and household water (Lantagne et al., 2006).The granular type of media filters for household bucket filters, drum or barrel filters are the most effective at reducing turbidity and enteric bacteria by 90%, larger parasites by 99% and enteric viruses by 50% to 90% (Sobsey, 2002; Potgieter, 2007). Slow sand filters, fibre, fabric and membrane filters, porous ceramic filters and diatomaceous earth filters are alternative filters that have been tested and used for household water treatment in developing countries (Potgieter, 2007). Some of the tested filters in developing countries are discussed below.

The BioSand Filter (BSF) is a slow-sand filter adapted for household use. The most widely used version of the BSF is a concrete container approximately 0.9 metre tall and 0.3 metre square, filled with sand. The water level is maintained at 50 to 60 mm above the sand layer by setting the height of the outlet pipe. This shallow water layer allows a bioactive layer to grow on top of the sand, which helps reduce disease-causing organisms. A plate with holes is placed on the top of the sand to prevent disruption of the bioactive layer when water is added to the system. Users simply pour water into the BSF, and collect finished water from the outlet pipe in a bucket. Water seeps through slow sand filters at rates of 0.1 to 0.2 m/h. Slow sand filters are more effective than rapid filters at removing particulates and microbial contaminants and are also simpler to operate. They do not require backwashing as frequently as rapid sand filters. Thus, the technology is low cost and low maintenance, but requires sufficient land area (Lantagne et al., 2006; UNICEF, 2008b). In laboratory and field testing, the BSF consistently reduces bacteria, on average, by 81-100 percent and protozoa by 99.98-100 percent. However, its effectiveness against viruses is low and its lack of residual protection may lead to recontamination (Lantagne et al., 2006).

Ceramic filtration is the use of porous ceramic (fired clay) to filter microbes or other contaminants from drinking water. Ceramic filters have traditionally been used for water treatment throughout the world. Most modern ceramic filters are in the form of vessels or hollow cylindrical "candles". Water generally passes from the exterior of the candle to the inside, although some porous clay filters are designed to filter water from the inside to the outside. Many commercially produced ceramic filters are impregnated with silver to act as a bacteriostatic agent and prevent biofilm formation on the filter surface and excessive microbial levels in the product water (Sobsey, 2002). The filter removes 99.99 percent of protozoa by mechanical processes (UNICEF, 2008b). Brown (2007) reported in his study in Cambodia that ceramic water purifier reduced *E. coli* up to 99.99%, in drinking water and contributed to the reduction of diarrhoeal disease by approximately 40% in users. However, the effectiveness of the filter in inactivating or removing viruses is unknown (Lantagne et al., 2006). In addition there may be a recontamination of stored water since there is there is no chlorine residual (UNICEF, 2008b).

Household chlorination: Chlorine is the most widely used and the most affordable of the drinking water disinfectants (Sobsey, 2002; Lantagne et al., 2006). The source of chlorine can be sodium hypochlorite. The sodium hypochlorite solution is packaged in a bottle with directions instructing users to add one full bottle cap of the solution to clear water (or two caps to turbid water) in a standard-sized storage container of 20 l; agitate; and wait 30 min before drinking (Lantagne et al., 2006). At concentrations used in household water treatment and safe storage programs with low turbidity water, chlorine effectively inactivates bacteria and some viruses (American Water Works Association, 1999) and thereby prevents waterborne diseases such as cholera, typhoid and dysentery (WCC, 2008). Unlike other technologies, chlorine disinfection has a residual effect, it continues to protect against the re-contamination of water over a period of time (Montgomery and Elimelech, 2007; UNICEF, 2008b).

Studies have showed that the use of sodium hypochlorite has improved the microbiological quality of drinking water and reduced the risk of diarrhoeal disease (Semenza et al., 1998; Quick et al., 2002; Sobsey et al., 2003; Luby et al., 2004; Potgieter, 2007). Recently, a study carried out in rural communities of South Africa indicated that sodium hypochlorite solutions effectively reduced the numbers of indicator microorganisms to undetectable counts in drinking water (Potgieter et al., 2008). An intervention to decrease contamination of water conducted in rural South India indicated a significant reduction of thermotolerant coliform in water samples ($p<0.001$). However, it is not effective at inactivating some protozoa, such as *Cryptosporidium* and *Giardia* (Sobsey, 2002; WCC, 2008; Firth et al., 2010).

Other disadvantages are that high levels of turbidity can protect microorganisms from the effects of disinfection, stimulate the growth of bacteria, and give rise to a significant chlorine demand. Effective disinfection requires that turbidity be less than 5 NTU (UNICEF, 2008b). A study by LeChavallier et al. (1981) showed that coliforms in high turbidity water (13 NTU) were reduced by 80% from their original concentration after chlorination, while coliforms in low turbidity water (1.5 NTU) in Bolivia were undetectable after chlorination (Schafer, 2010). Chlorine is currently manufactured, packaged, and distributed by local microenterprises. For example, Population Service International (PSI), a NGO that has utilized a social marketing model to implement the Safe water System (**SWS)** in a number of developing world countries branded the chlorine product "Chlorin" in Zambia, "WaterGuard" in Tanzania and "Sûr'Eau" in Madagascar and Rwanda (Montgomery and Elimelech, 2007; USAID, 2008).

The CDC (2001) and WHO (2004) recommend the addition of either 0.5% or 1% stabilized sodium hypochlorite solution to obtain a free chlorine residual of 0.5 to 1.5 mg/l after at least 30 min contact time at a $pH<8.0$. In South Africa, the Department of Health's (DOH) recommendations do not specify the free chlorine residual concentration. However, the DOH recommends the addition of 5 ml of 3.5 % stabilized concentration of sodium hypochlorite solution to a 20 or 25 l storage container (Lantagne et al., 2006; Potgieter, 2007).There has been overwhelming evidence that POU water treatment reduces diarrhoea prevalence (Fewtrell et al., 2005; Arnold and Colford, 2007; Clasen et al., 2007). Sûr'Eau, a chlorine-based POU water disinfection product has been available in Rwanda since 2002, and is currently sold through health centres and commercial outlets throughout the country. However, its use in rural areas of the country is limited (USAID, 2008).

Combined point-of-use treatment systems: The combined application of chemical coagulation-flocculation, filtration and chlorine disinfection is widely practiced for community water treatment in developing countries, especially for surface sources of drinking water. In combination, these processes have been shown to dramatically reduce microbial contaminants in drinking water, produce water that meets international guidelines and national standards for microbial quality and embody the principles of a multiple barrier approach to drinking water quality (Sobsey, 2002).

A particular challenge for most household-based water treatment technologies is high turbidity. Turbidity is often managed by flocculation/coagulation using common substances such as alum which is a relatively low-cost option. Such forms of assisted sedimentation reduce the levels of certain microbial pathogens, especially protozoa which may otherwise present a challenge to chemical disinfectants. Home-based treatment can be a more sustainable solution than communal systems because people are more motivated to correctly operate and maintain their own systems than they are with communal ones. Most importantly, home water treatment on its own cannot significantly and sustainably reduce the incidence of water-related diseases unless water is stored and used safely and all household members practice good hygiene (UNICEF, 2008b). Additional interventions include sanitation and health education where people were informed and educated on hygiene and water handling practices (Sobsey et al., 2003; Quick et al., 2004; Potgieter, 2007).

2.6 Drinking water quality, sanitation and hygiene practices

Numerous studies have definitively shown that sanitation and hygiene behaviours are equally important in disease prevention (Esrey et al., 1991; Macy and Lochery, 1997). Improvements in the quality of water, the disposal of excreta, and the delivery of general hygiene education are all important factors in achieving reductions in diarrhoea morbidity and mortality rates (WHO, 1999, Bartram and Cairncross, 2010). Improving sanitation in rural communities should include safe disposal of human waste through encouraging the use of a pit latrine, safe disposal of children's stool in latrines or through burial in the ground, ensuring proper use of latrines, keeping the latrines clean and daily disinfection of the soil of existing or new structures with a 0.2% chlorine solution. It also includes hand washing stations with soap and adequate water for hand washing near the latrines (UNICEF, 2010).

A simple pit latrine, one of the most basic forms of household sanitation, offers an inexpensive alternative to a sewage system. One of the major challenges with sanitation is developing and implementing innovative, user-friendly, low cost systems (Montgomery and Elimelech, 2007). However, some evidence has linked the standard latrine to contamination of groundwater by bacteria and nutrients. In addition, traditional latrines may harbour offensive odours and flies. The ventilated improved pit latrine improves on the standard design by allowing odours to escape, preventing flies from entering, and in many cases sealing the pit to prevent groundwater contamination (Montgomery and Elimelech, 2007).

In addition, basic hygiene practices, especially hand washing was shown to be effective intervention in the reduction of waterborne diseases in developing countries. Human faecal contamination from children and adults who do not wash their hands after using the toilet can contribute to secondary contamination of household stored drinking water (Potgieter, 2007). Several studies have indicated that *E. coli* can survive for 10 minutes, *Klebsiella spp* for 2.5 hours and *Shigella sonnei* for up to 3 hours on unwashed hands which can contaminate water and food in the household (Potgieter, 2007). Consequently, washing hands practices with soap at critical times: after defecating, after cleaning a child who has defecated and before eating or preparing food were shown to be effective in the reduction of diarrhoeal diseases (Potgieter, 2007; Khale and Dyalchand, 2008; Cairncross et al., 2010). A recent study in rural Bangladesh showed the effectiveness of washing hands with soap in reducing childhood diarrhoea, compared to households where people prepared food without washing hands. Children living in households where hands were washed before preparing food had less diarrhoea (Odds Ratio (OR) = 0.30; 95%, confidence interval (CI) = 0.19–0.47). The same trend was shown in households where residents washed hands with soap after defecation (OR = 0.45; 95% CI = 0.26–0.77 (Luby et al., 2011)). Hoque (2003) showed that soap, ash and soil were equally effective hand washing reagents. However, washed hands should not be dried with dirty cloths since, recontamination of hands occurred (Potgieter, 2007).

Improvements in the quality and availability of water, the disposal of excreta, and the delivery of general hygiene education are all important factors in achieving reductions in diarrhoea related morbidity and mortality rates (WHO, 1999). Proper education should be provided to people from rural communities to promote the correct hygiene practices and these communities should be informed on the transmission risk and the causes of waterborne diseases (Banda et al., 2006). Information about water quality and available methods of improving it and hygiene behaviour provided through home visits, health education classes, awareness campaigns or hygiene promotion programs has been shown to be an effective instrument (Cairncross et al., 2006; O'Reilly et al., 2007). However, most studies on population's knowledge and practices conducted in rural communities showed that they were not aware of safe water handling in the households (Banda et al., 2006).

2.7 National Water and Sanitation Policy (WSP)

The National Water and Sanitation Policy (WSP) in Rwanda, was developed on the sector-based policy project on water and sanitation and revised in 2004. The policy defines guidelines for efficient use of resources and also integrates new aspects such as decentralization, participatory approach, privatization and funding through programme approach. A recent Water Supply and Sanitation (WSS) policy was launched in February 2010. The need to update the WSS policy arose from the fact that significant institutional reforms have substantially changed the sector context. The 2010 policy's scope has changed by focusing on water and sanitation only. It no longer covers water resources management (MININFRA, 2010). The policy is in harmony with MDGs, the Economic Development and Poverty Reduction Strategy (EDPRS) objectives and Vision 2020 which states that all of its population will have access to safe drinkable water and to sanitation services by 2020 (MININFRA, 2010). However, the 2006 water and sanitation sector performance report indicates slight increase in water supply between 2001 and 2005 from 58% to 62% respectively, but the supply did not correlate with increased area coverage of water infrastructure in urban areas because most returnees and immigrants, built their houses within old settlements, next to old plots, so that they could easily connect their houses to electricity and water supplies (Sano, 2007).

The EDPRS aims at increasing the proportion of the rural population living within 500m of an improved water source from 64% to 85% and to raise the proportion of the urban population residing within 200 m of an improved water source from 69% to 100%. As regards to sanitation, the plans are that the proportion of rural households with latrines complying with health norms will increase from 38% to 65% by 2012 (MININFRA, 2010).

Many problems in this sector are encountered which include the institutional framework for the coordination of water resources management and mechanisms for the monitoring and assessments. There is also insufficient infrastructure whereby more than a third of drinking water supply infrastructures have to be rehabilitated, insufficient expertise in that area, which requires the use of consultants outside the country. Further there is insufficient data of the actual situation of sector and limited intervention of the private sector (Haguma et al., 2008).

2.7.1 Responsibility for water supply and sanitation (WSS)

The Ministry of Infrastructure (MININFRA) through its Water and Sanitation sector with operational autonomy is responsible of determining water policies and strategies in Rwanda. The Ministry of Lands, Environment, Forests, Water and Mines (MINITER), through its water and sanitation sector, is responsible for determining water policies and strategies in Rwanda and monitoring drinking water quality and promoting user awareness. The Ministry of Infrastructure (MININFRA) supports Districts in the construction of water supply systems, latrines and hygiene promotion with the support of UNICEF. The Ministry of Local Government, Good Governance, Rural Development and Social Affairs (MINALOC) is responsible of accompanying local participatory planning processes, applying the government's Community Development Policy (The free encyclopaedia, 2009). Additionally, achieving the sector's targets implies coordination of all key players including in particular the Ministry of Health, the urban water and sewerage Utility (RWASCO) and the Rwanda Utility Regulatory Agency (RURA) and the Ministry of Natural Resources as well as the development partners (MININFRA, 2010). Table 2.3 compares the Rwandan water and sanitation and South African policies.

Table 2.3: Comparison of Rwandan and South African National water supply and sanitation policies (DWAF, 1994; MININFRA 2010)

WSP RWANDA	WSP SOUTH AFRICA
PRINCIPLES	
• Each person has equal right to access basic water services " some to all" rather than "all for some" • The beneficiaries of water supply and sanitation services shall be actively involved in planning, decision making and oversight throughout the project implementation cycle. • The responsibility for service delivery is vested at the decentralized level • Sanitation and hygiene activities shall be developed through strategic cooperation with the health and education sectors • All sector activities shall be designed and implemented in a way to ensure equal participation and representation of men and women. • The water and sanitation sector gives preferential consideration to service delivery in grouped settlements, taking into account the changing of habitat structure.	• "Some for all", rather than "All for some: priority in planning and allocation of public funds is given to those who are presently inadequately served. • The user pays: This is a central principle to ensure sustainable and equitable development, as well as efficient and effective management • Development should be demand driven and community based: Decision making and control is devolved as far as possible to accountable local structures. • Basic services are a human right, a right to a level of services adequate to provide a healthy environment. • Equitable regional allocation of development resources: The limited national resources available to support the provision of basic services should be equitably distributed among regions, taking account of population and level of development. • Water has economic value: The way in which water and sanitation services are provided must reflect the growing scarcity of good quality water in South Africa in a manner which reflects their value and does not undermine long term sustainability and economic growth. • Integrated development: Co-ordination is necessary with all tiers of government and other involved parties and maximum direct and indirect benefit must be derived from development in • Environmental integrity: It is necessary to ensure that the environment is considered and protected in all development activities.

The microbiological quality of drinking water is implicated in the spread of waterborne disease, particularly in rural communities. This chapter reviewed a varied selection of literature on drinking water contamination at the source as well as the point-of-use and a variety of treatment methods that have been developed to improve the microbiological quality of drinking water. The aim of this study was therefore to determine the microbiological quality of water at the source and at the household level after treatment, women's water handling practices in rural communities of Masaka in Rwanda and their significance to the prevalence of waterborne diseases in the study areas. The results obtained from this study would be used to provide information to the government, researchers and practitioners including water providers and water users and donors about the constraints that exist in water provision and sanitation in rural Rwanda and the possible remedial measures to deal with them. Chapter 3 details the methodology employed for this study.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Overview

This study assessed the microbiological quality of Nyabarongo River as a water source used by the communities of Rusheshe and Ayabaraya in Masaka of Kicukiro District, the women's knowledge, attitudes and practices (KAP) on water usage and waterborne diseases and the prevalence of waterborne diseases in the study areas. The fieldwork was carried out in 3 months from January to March 2011 and consisted of three phases of collecting data: collecting water samples for microbiological analysis, collecting questionnaire data for women's KAP on water usage and waterborne diseases using a structured questionnaire (Appendix 4) and to gather retrospective data on diarrhoeal diseases using a checklist (Appendix 5).

3.2 Study design

This was a quantitative cross sectional study.

3.3 Study area

Two rural communities in Masaka were selected for this study. These two communities (Rusheshe and Ayabaraya) are located in Masaka Sector (2^{o}02'41.21"S; 30^{o}12'34.93"E), Kicukiro District in Rwanda. Masaka is located in the South East of Kicukiro District as shown in Figure 1:1 in Kigali city, about 20 km from the city centre. Rusheshe and Ayabaraya are rural communities with 1,095 households and a total of 7,774 residents, 4,627 from Rusheshe and 3,147 from Ayabaraya. The areas are characterized by two dry seasons (a short dry season: December, January, February and a longer dry season: June, July, August, September) and two seasons of rain (short season of rain: October, November and (a longer season of rain: March, April, May). These two cells are situated along Nyabarongo River (Figure 3:1) and are occupied by informal settlements. In 2006, there has been an outbreak of cholera in the Rusheshe and Ayabaraya communities and this outbreak was linked to the use of contaminated water from Nyabarongo River (Weinberger, 2006), which is why these areas where selected for the current study to emphasise the need of safe water in these rural areas.

Figure 3.1: Map showing Nyabarongo River, Rwanda

The Nyabarongo River (Figure 3.1) originates in Nyungwe Forest Reserves in South-west Rwanda and is now believed to be the true source of Nile River. It flows southwards to meet the Akanyaru River to make up Rusumo River, which is later called Akagera River, the great river that defines the border with Tanzania which flows into Lake Victoria. Nyabarongo River water is used for drinking, cooking and bathing in the Kigali area (Sano, 2007).

3.4 Study population and sample

Residents of two communities of Masaka sector (Ayabaraya and Rusheshe) in Kicukiro District, Kigali City participated in this study. A systematic random sampling was used to select households to participate in the KAP study regarding water usage and waterborne diseases.

A total of three hundred and twenty eight (328) households were systematically sampled. This number is 30% of the households, and hence, a reasonable representation of the total of 1095 households in the two communities. Hundred and ninety-seven (197) households representing 60% of the total sample in Rusheshe and 131 (40%) in Ayabaraya were selected.

The first household of each day of data collection was chosen randomly then every third household was selected and if the resident of the third household did not participate, the next in the sequence after that one was selected. In addition a purposive sampling was utilized to select the participants in the interview process where only women aged between 18 and 55 years were selected to participate in the study. Women are the primary caregivers involved in domestic duties like fetching water, cooking, in maintaining hygiene and sanitation. Ten (10) out of 328 households which participated in the study interview were randomly selected for water sample collection to analyse the microbiological quality of drinking water at the point of use.

3.4.1 Inclusion criteria

- People who are resident in Rusheshe and Ayabaraya
- Only women between 18 and 55 years old were chosen to participate in the interview on KAP about water handling at home and waterborne diseases.
- Women who agreed to participate in the interview and who signed an Informed Consent (Appendix 1)
- Water samples were collected from households which participated in the study interview used Nyabarongo River as their water source and their treated drinking water using either a household Slow Sand Filter or Sûr'Eau**.**

3.5 Water sampling procedures

Fifteen (15) water samples were taken from Nyabarongo River and 20 from participative households using it as their water source from Rusheshe and Ayabaraya communities. Samples were collected in accordance with the Department of Water Affairs and Forestry (DWAF) sampling guide (DWAF, 2000). Water samples for microbiological analysis were collected in non-reactive borosilicate glass bottles of 100 ml capacity (the minimum volume of sample sufficient to allow analysis at the limits of detection stipulated in regulations) (Robertson et al., 2002) supplied by Kigali Water Laboratory (KWL), each had been sterilised at 121°C to prevent contamination of samples after collection. The water sample bottles were labelled with permanent ink prior to sample collection with the site name, date, time and the name of the person collecting the samples.

3.5.1 River water sampling

Triplicate samples were collected during the period of January 2011 from five sites: Site1, Site2, Site 3, Site 4, and Site 5 on the Nyabarongo River for microbiological examination. Sites 1 and 2 are located in Ayabaraya community and Sites 3, 4 and 5 in Rusheshe community and these sites were located at approximately 2 km from each other (Figure 3.2). At each site, water samples were taken from three points specifically, before the water collection point, at the exact water collection point and after the water collection point. Samples were taken directly from the river in accordance with the DWAF sampling guide (DWAF, 2000). The sampling bottle was not filled up to the brim; 25 mm space was left for shaking of the bottle before analysing.

1, 2, 3, 4, 5: Water sampling sites on the Nyabarongo River; ⌂: Study communities in Rusheshe and Ayabaraya communities

Figure 3.2: Geographical location showing the sampling sites and the studied communities (Google earth, 2011)

3.5.2 Household water sampling

Twenty water samples were collected from 10 households selected randomly, for turbidity and microbiological analysis. At each household, two samples were collected on two different days of the week. Twelve (12) samples of freshly filtered water were collected from the Slow Sand Filter (SSF) tap in sterile, 100 ml bottles which were stored in ice packs until returned to the laboratory. In addition, 8 samples of Sûr'Eau treated water were collected from 20 litre jerry cans into 100 ml sterilized bottles. Water samples were transported in ice packs to retain water samples at $4^{o}C$. Temperature was measured on delivery to the Kigali Water Laboratory (KWL), a laboratory situated within 30 minutes from the study area where they were processed immediately.

3.6 Laboratory water analysis methods

Indicator bacteria to assess the microbiological quality of the water samples included total coliform and faecal coliform bacteria. These indicator organisms were analysed in the River water as well as the household water storage container samples.

Both total coliform bacteria and faecal coliform bacteria were enumerated on Lauryl sulphate broth medium prepared according to the manufacturer's instructions (Merck, Darmstadt, Germany). Water samples were analysed in triplicate for the presence of total coliform and faecal coliform using the membrane filtration technique. The raw water was diluted up to up to 10^{-3}, and then a 100 ml of water sample was filtered through a sterile 47-mm- diameter membrane filter inserted in a filtration unit. The membrane filters were placed right side up on the Petri Dish containing an absorbent pad soaked in the culture medium. Plates for enumeration of total coliform bacteria were inverted and incubated at $37^{o}C$ for 24 hours. Metallic green colonies were counted as positive colonies for total coliform bacteria. Faecal coliform bacteria were inverted and incubated aerobically at $44.5^{o}C$ for 24 hours. Dark blue or violet colonies were considered positive colonies.

The turbidity levels in Nephelometric Turbidity Units (NTUs) of each household water sample were determined using a portable H193703 Microprocessor turbidity meter (HANNA Instruments, German) which was calibrated according to the manufacturer's instructions. .

3.7 Knowledge, attitudes and practices (KAP) survey

During January 2011, data for the women's KAP regarding water usage was collected using a structured questionnaire (Appendix 4). The questionnaire contained closed - ended and open-ended questions. It was based on factors discussed in the literature review (Sobsey, 2002; Lantagne et al., 2006; UNICEF, 2008a), and was modified from other questionnaires used in previous studies (Mahamud, 2005; Potgieter, 2007). All closed-ended responses were coded prior to data collection in order to make data entry simple and efficient, while open-ended questions were coded after data collection. The original questionnaire was formulated in English and then translated into Kinyarwanda, the local language (Appendix 4).

The questionnaire comprised 29 questions divided into 4 sections:

- Section 1 gathered personal and demographic information on the participant in order to establish if there would be any correlation between these variables and the participant's KAP regarding water usage and waterborne diseases.
- Section 2 gathered information on water sources used, collection, storage and treatment before use.
- Section 3 focused on information concerning hygiene and sanitation practices and their potential to cause waterborne diseases, such as presence of toilets, washing hands practices and other related information
- Section 4 collected information on the participant's knowledge of waterborne diseases, their causes and prevention practices at the household level as well as the community level and on the awareness of home treatment for diarrhoea.

3.7.1 Administration of questionnaire

Before the collection of data, five third year students from the Environmental Health Department in the Kigali Health Institute (KHI) were recruited as interviewers and were briefed on the nature and the purpose of the study. The questionnaire was explained to the interviewers by going through question by question together with instructions about the questions and the process of the interview, to clarify any final ambiguities.

The questionnaire was pre-tested with a convenience sample of 10 participants selected from the study households. The purpose of the pilot study, as per Hicks (2004), was to ascertain if the information collected in the interview will be collected (used) correctly, and if all the instructions are clear and easy to understand by the interviewers as well as interviewees. The pilot study, in addition, helped to determine the amount of time to allot to the actual interviews. Based on the results, the interview was estimated to last 35 minutes on average.

The study made use of face-to-face interview where people were interviewed in their homes. Interviewers administered structured questionnaires to one adult female person in each household. Where there were more than one woman aged between 18 and 55 year, one of them, the primary caregiver and most involved in water usage, was selected to respond to the questions. Information collected included basic demographic details, sources of water, treatment methods for drinking water, storage practices, availability of toilets, hand washing practices and knowledge regarding causes of diarrhoea.

3.8 Prevalence of waterborne diseases

Information regarding the prevalence of waterborne diseases was collected using retrospective records from the Masaka Health Centre, which services both study areas. Retrospective data dated from January to December 2010 was collected. The clinic records were noted with focus on the patients from the study areas. All the information was gathered using the clinic checklist (Appendix 5) adapted from a previous study on prevalence of waterborne diseases in Kenya (Chabalala and Mamo, 2001). The checklist combined information of the patients, including age, address, date of consultation, reason for visit, symptoms and treatments offered at the Health Centre.

3.9 Statistical data analysis methods

Data was initially captured into a Microsoft Excel where the process of cleaning and editing of the data was done. Statistical analysis was performed using SPSS Predictive Analytic Software (PASW) Statistics version 18.0 (IBM, Somers, NY) and STATA Release (Version 11.0, College Station, Texas USA).

Results from the laboratory were organized in data-recording sheets and were compared to the standards set by the World Health Organization (WHO) and Rwanda (WHO, 2006; RBS, 2010). The data obtained was subjected to descriptive statistics to evaluate how results are distributed around the mean, minimum and maximum value. In cases where microbial counts were described as less than 1cfu/ml, the counts were treated as 1 in order to facilitate the calculations. One-way analysis of variance (ANOVA) tests were used to compare the means of parameters and Student's t test was used to compare the means of microbial parameters for the Nyabarongo River water source and the household water after using SSF and Sûr'Eau as treatment methods. The coefficient of correlation between FCC and the turbidity values was calculated by the Pearson correlations test.

All parameters in the household questionnaires used on the baseline characteristics were categorically describing the water handling, hygiene and sanitation practices and waterborne diseases awareness at the household level. Data were summarised making use of frequencies, percentages and cross-tabulations. Descriptive analysis was followed by bivariate statistics. The Pearson's chi-square tests were performed to determine whether there was a statistically significant relationship between the independent variables (water treatment practices, storage container cleaning and ways of cleaning the storage container, hand washing practices) and the dependent variable/outcome (diarrhoea, washing hands practice). Logistic regression models were then used to investigate the relationship between binary outcome variables and adjusted for relevant covariates. We decided *a priori* to include age as a covariable in our final models and tested a range of other covariates including, water source, water storage container cleaning practices (how often the water storage container was cleaned in the study households) and importance of washing hands. Odds Ratios (OR) and Confidence intervals (CI) of 95% were calculated. All reported p-values are two-tailed and statistical significance was set at 0.05.

3.10 Ethical consideration

The study project was approved by the Faculty of Health Sciences Research Committee (FRC) at the Durban University of Technology (DUT), where the study is registered. Authorization to conduct the study was obtained from the Department of Health and local authorities of Kicukiro District and Masaka Health Centre (Appendices 2 and 3 respectively). In each of the two study communities, a selected participant received a letter informing that a research project was being conducted, a description of the study, the voluntary nature of participation, and assurance of privacy and confidentiality. Every participant signed informed consent (Appendix 1). Informed consent was formulated in English and then translated into Kinyarwanda, the local language of the community.

All participation was voluntary and withdrawal from the study was possible on request at any point in the study. No financial incentives were provided for participation in this study as it had no harm on the participants. All data collected was treated as strictly confidential and maintained under locked storage and only available to the research team.

This chapter detailed the methodology employed to conduct this study. The study was a sequential mixed method, descriptive cross sectional study that generated quantitative data. The following chapter presents the findings of the study.

CHAPTER 4: RESULTS

This chapter presents results of this study that were obtained from water analyses, retrospective clinic records and KAP questionnaires from the participants of the study. A comprehensive discussion of the results will follow in Chapter Five.

4.1 Microbiological quality of water

The results indicated that all the parameters assessed for microbiological quality for both river samples and household storage containers in the study areas, exceeded the Rwandan recommended guideline value of 0 cfu/100 ml for total and faecal coliform bacteria counts in drinking water (RBS, 2010). Table 4.1 shows the mean counts at all the sampling points from the Nyabarongo River. Total coliform counts were 5.8 $x10^3$ cfu/100ml before the collection point, $8.2x10^3$ cfu/100ml at the point of collection, and $7x10^3$cfu/100 ml after the point of collection. Similarly, the mean counts for faecal coliform were 1164 cfu/100 ml before the collection point, 2660 cfu/100 ml at the collection point and1232 cfu/100 ml after the collection point.

Table 4.2 shows the results for household water. The mean counts of total coliforms were 284 cfu/100ml for household filtered water and 329 cfu/100ml for Sûr'Eau treated water. The mean counts for faecal coliforms were 75 cfu/100ml for household filtered water and 122 cfu/100ml for Sûr'Eau treated water. Filtered water had turbidity mean value of 18 NTU while Sûr'Eau treated water had turbidity mean value of 191 NTU.

Table 4.1: Mean values (95% confidence intervals) for microbiological indicators for water samples collected from Nyabarongo River *

Water quality parameter		Point of sampling on Nyabarongo River**			
		Before	At	After	Overall
Total coliforms *(cfu/100 ml)*	Max	$1x10^4$	$2x10^4$	$1x10^4$	$2x10^4$
	Min	$2x10^3$	$3x10^3$	$3x10^3$	$2x10^3$
	Std. dev	2864	7190	3082	4567
	Mean	$5.8x\ 10^3$	$8.2x10^3$	$7x10^3$	$7x10^3$
	95% CI	2244; 9356	0; 17128	3173; 10827	4471; 9529
Faecal coliforms[1] *(cfu/100 ml)*	Max	$5x10^3$	$6x10^3$	$5x10^3$	$6x10^3$
	Min	20	$1x10^2$	60	20
	Std. dev	2152	2724	2120	2288
	Mean	1164	2660	1232	1685
	95% CI	0; 3836	0; 6042	0; 3865	418; 2953

[1] Results of <1 treated as 1 for calculation purposes; * n = 5 samples at each sampling point; **water samples were taken before, at and after the point of water collection used by the communities

Table 4.2: Mean values (95% confidence intervals) for microbiological indicators and turbidity values for water samples collected from household treated water

Water quality parameter		Type of water treatment		
		Filtered water using SSF(n=12)	Water treated with Sûr'Eau (n=8)	Rwandan standards[1]
Total coliforms *(cfu/100ml*	Max	$1x10^3$	$1x10^3$	Zero
	Min	10	1	
	Std. dev	348	433.4	
	Mean	284	329	
	95%CI	63; 505	0; 691	
Faecal coliforms[2] *(cfu/100ml)*	Max	$7x10^2$	$4x10^2$	Zero cfu/100ml
	Min	1	1	
	Std. dev	111.8	237.7	
	Mean	75	122	
	95%CI	4;146	0; 320	
Turbidity (NTU)	Max	52.1	426	0.1 NTU
	Min	5.24	4.45	
	Std. dev	15.5	171.9	
	Mean	18	191	
	95%CI	8;27	47;334	

[1]Source: RBS, 2010; [2] Results of <1 treated as 1 for calculation purposes

Table 4.3 shows the number of samples collected from households which used SSF to treat water before use, that had 1 and above cfu/100 ml. Twenty five percent (25%) of all samples of filtered water had less than 1 cfu/100ml faecal coliform counts. Of 8 samples taken from households using Sûr'Eau for their water treatment, samples which had less than 1cfu/100ml were 2(25%) for total coliform counts and 3(37%) for faecal coliform counts.

Table 4.3: Effectiveness of Slow Sand filter and Sûr'Eau at the household level for coliform removal in water

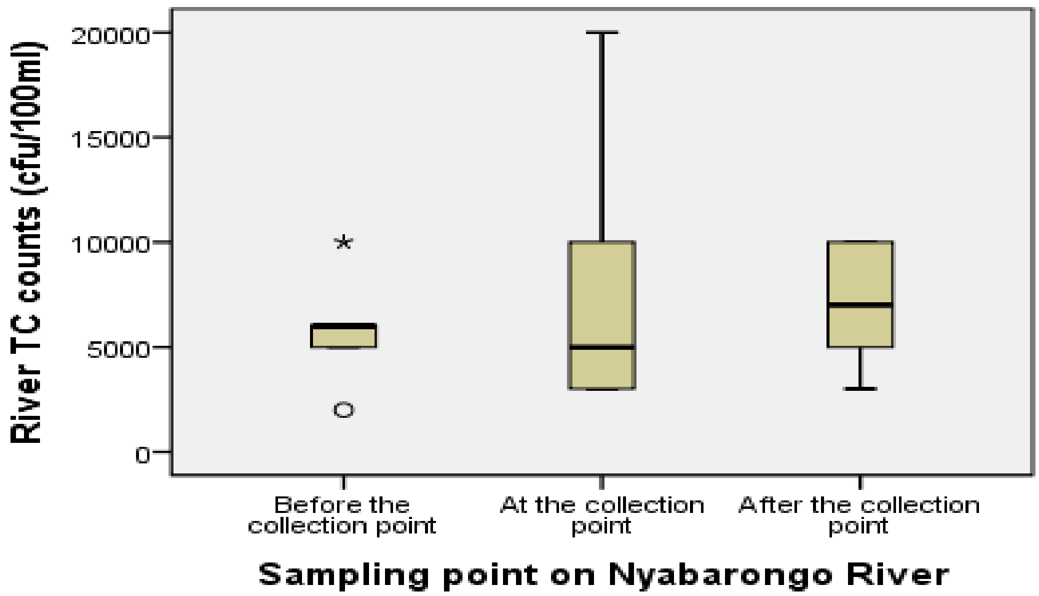
Coliform counts (cfu/100 ml)	Treatment methods used in the households			
	SSF water (n =12)		Sûr'Eau treated water (n =8)	
	TC n (%)	FC n (%)	TC n (%)	FC n (%)
< 1	0 (0)	3 (25)	2 (25)	3 (37.5)
1 - 10	1 (8)	2 (17)	0 (0)	1 (12.5)
11 - 100	6 (50)	6 (50)	3 (37.5)	3 (37.5)
101 -1000	5 (42)	1 (8)	3 (37.5)	1 (12.5)

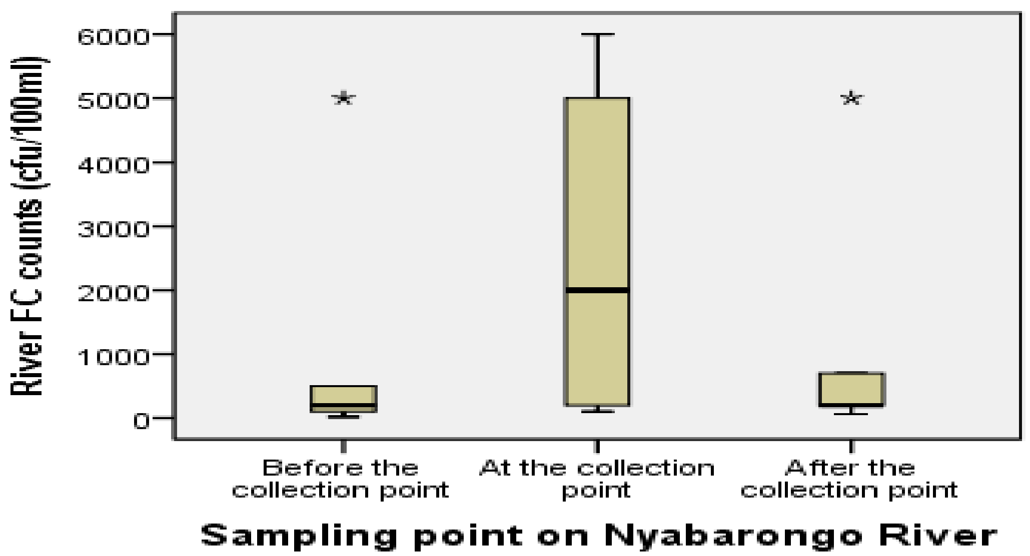
A statistical analysis was performed to see if differences exist between parameters for samples taken directly from the different sampling points of the river, samples taken from

SSF and from Sûr'Eau treated water storage container. In order to determine this, Analysis Of Variance (ANOVA) was performed. The results indicated that there were no statistical significant differences of means for total coliform and faecal coliform mean counts (p = 0.51 (TC) and p = 0.77 (FC) respectively), between samples taken directly from different sampling points on Nyabarongo River (Figure 4.1). Similarly, no statistical differences of means were observed for both total coliform and faecal coliform counts [p=0.80 (TC) and p = 0.56 (FC)] between samples taken from household storage containers. A significant statistical difference was observed for turbidity values between filtered water using SSF and Sûr'Eau treated water samples (p =0.002) (Figure 4.2).

Additionally, the results were analysed for the correlation between the turbidity values and total coliform and faecal coliform bacteria counts for household water samples. The correlation coefficient (r) indicated a relatively weak relationship between turbidity values and faecal coliforms bacteria counts (r = 0.25). Similarly, no significant correlation between turbidity values and total coliforms bacteria counts was observed (p = 0.73). The correlation coefficient (r) indicated a weak inverse relationship between the parameters (r= -0.08).

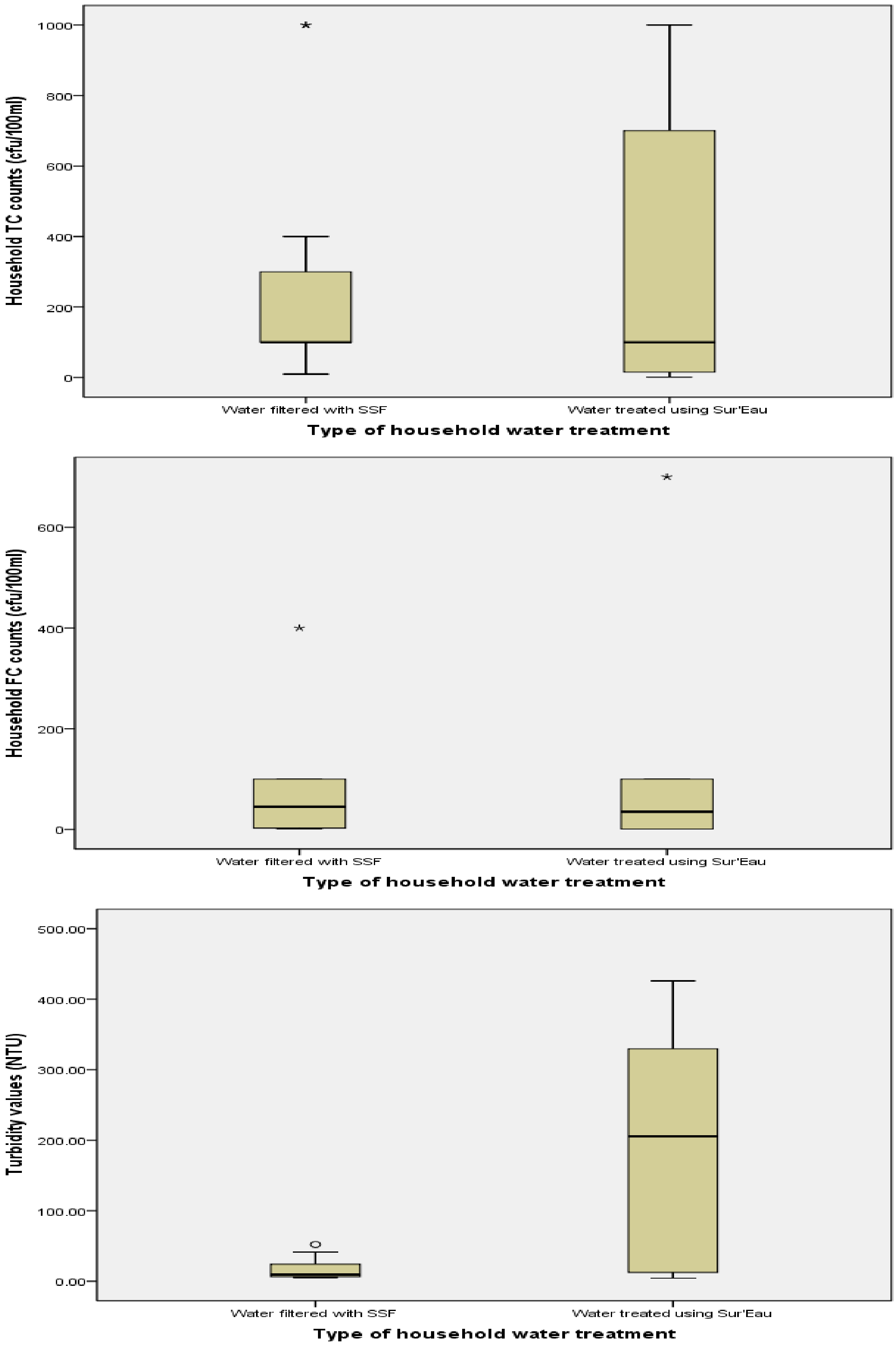
Further, the data were analysed to see if there were any differences of mean values of parameters between samples taken directly from the river and those from the households' storage containers. The results presented in Figure 4.3, indicated that total coliform mean values for samples taken from households storage containers were significantly lower than for those taken from the river (p < 0.05). Similarly, a statistical difference (p = 0.004) was found between the faecal coliform mean counts of the river and the samples from the household storage containers.





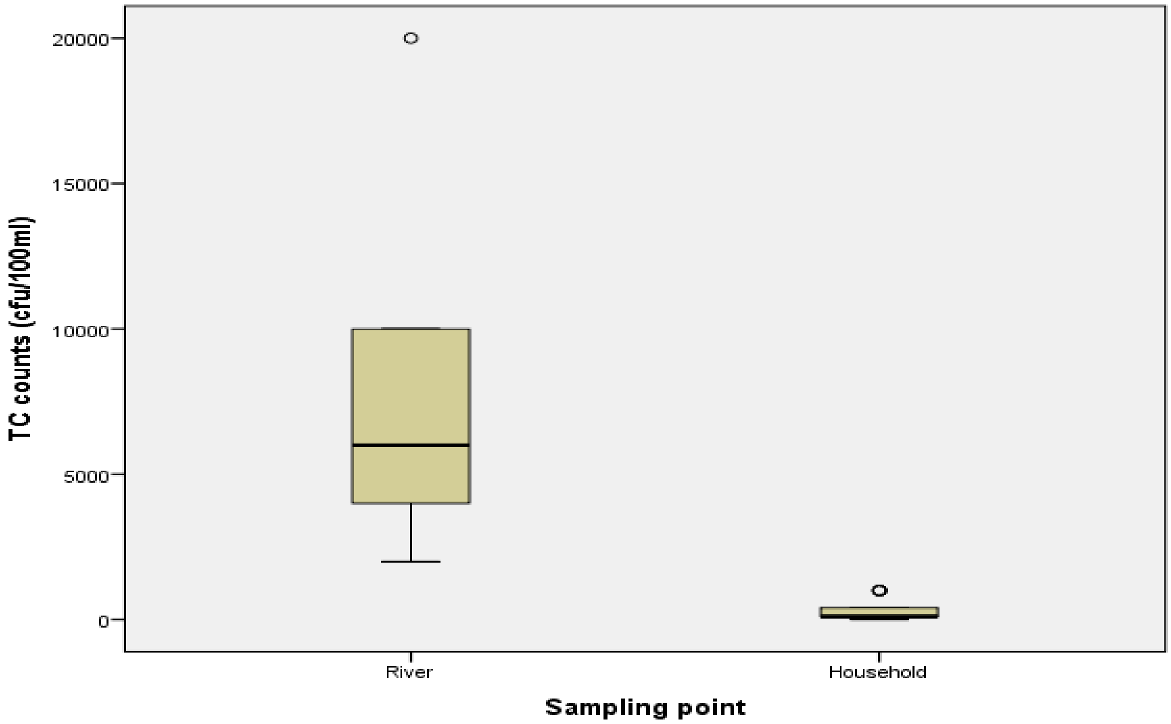
Comparisons of means for Nyabarongo River water samples. TC: total Coliform ($p = 0.51$); FC: Faecal Coliform ($p = 0.77$)

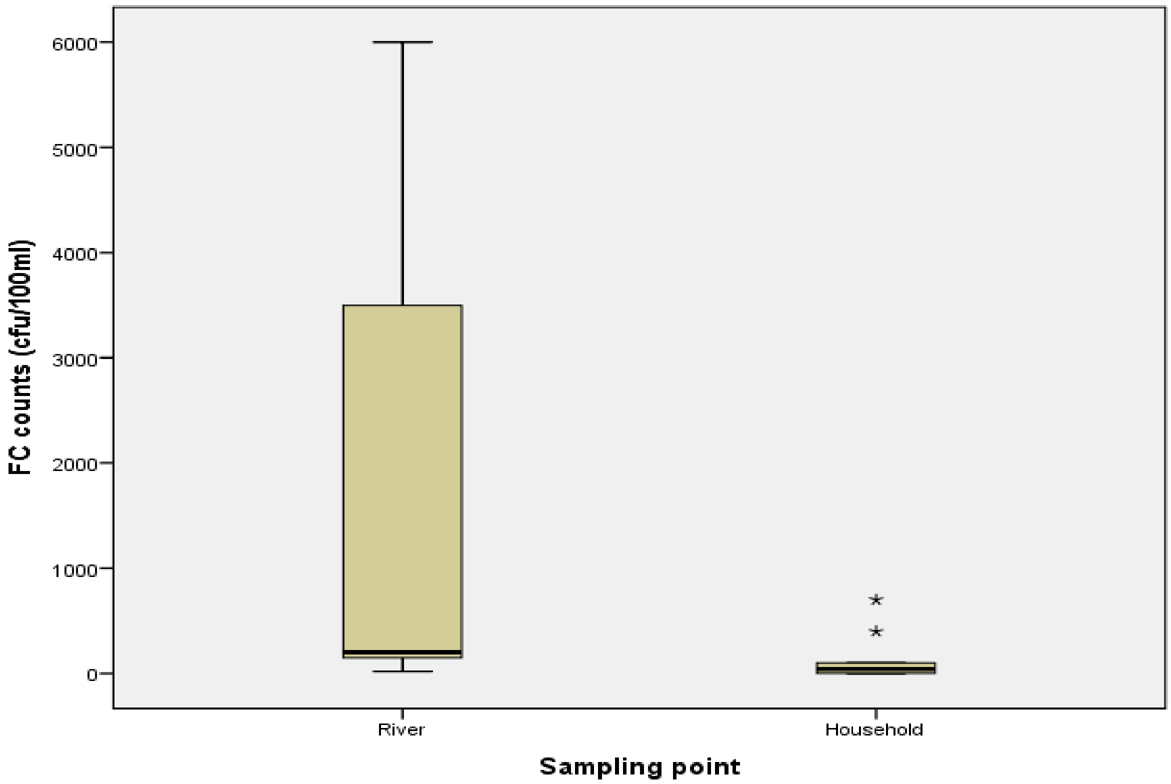
Figure 4.1: Results showing differences in means of total coliform and faecal coliform counts for Nyabarongo River (n= 15)



Comparisons of means for each household water treatment method. TC: total Coliform (p = 0.80); FC: Faecal Coliform (p =0.56); Turbidity (p =0.002); SSF: Slow Sand Filter

Figure 4.2: Results showing differences in means of total coliform, faecal coliform counts and turbidity values for filtered (n=12) and Sûr'Eau treated water (n= 8)





Comparisons of means for each sampling point using student's *t*-test. TC: total Coliform (p <0.05); FC: Faecal

Coliform (p = 0.004)

Figure 4.3: Results for total coliforms and faecal coliforms for Nyabarongo River water (n = 15) and household water (n = 20)

4.2 Prevalence of waterborne diseases in Rusheshe and Ayabaraya communities

Retrospective clinic records from Masaka Health centre were reviewed to identify patients with diarrhoeal diseases reported in 2010. Out of 2814 records reviewed, 160 (5.7%) cases were identified as diarrhoeal diseases from the two villages; 51% from Rusheshe and 49% from Ayabaraya (Table 4.5). However, clinic records did not specify diarrhoeal diseases, and instead reported the symptoms of diarrhoeal diseases and coded patients who visited the clinic either by bloody diarrhoea or by non-bloody diarrhoea.

Table 4.4 shows the frequency distribution of the individuals identified to have had symptoms of diarrhoeal diseases. The majority of patients, who visited the clinic with diarrhoeal diseases (56%), were children under five years. The table also shows the sex distribution of the symptoms of diarrhoeal diseases. Table 4.4 indicates that 54% of the symptoms of diarrhoeal diseases victims were females, whereas 46% were males.

Table 4.4: Demographic data of the patients reported to Masaka Health centre in 2010 with diarrhoeal symptoms (n =160)

Data	N (%)
Community	
Rusheshe	82 (51)
Ayabaraya	78 (49)
Total	160 (100)
Age of patients with diarrhoea	
< 5	90 (56)
5 to 9	6 (4)
10 to 19	17 (11)
20 to 29	17 (11)
30 to 39	10 (6)
40 to 49	7 (4)
50 to 59	8 (5)
60 and above	5 (3)
Total	160 (100)
Gender of patients with diarrhoea	
Male	73 (46)
Female	87 (54)
Total	160 (100)

As shown in table 4.5, 90% visited the clinic with non-bloody diarrhoea, while 9% presented with bloody diarrhoea and 1% did not indicate the category for diarrhoea. Watery stool was identified as the leading diarrhoeal symptoms in Masaka health centre. Out of 160 patients with diarrhoeal symptoms, 143 (89%) had watery stool, 79 (49%) had fever. Dehydration and bloody stools contributed 11% (17) and 9% (15) respectively.

Table 4.5: Diarrhoeal symptoms of patients reported to Masaka health centre during 2010 (n=160)

Data	N (%)
Reasons for visit	
Non bloody diarrhoea	143 (90)
Bloody diarrhoea	15 (9)
Not recorded	2 (1)
Total	160 (100)
Symptoms	
Fever	79 (49)
Watery stools	143 (89)
Watery stools mixed with blood	15 (9)
Abdominal pain	44 (28)
Vomiting	25 (16)
Dehydration	17 (11)
Nausea	7 (4)

Figure 4.4 illustrates the general monthly data of the number of diarrhoeal diseases cases in the clinic from the study areas. The number of diarrhoea cases varies remarkably among the months of a year. On the whole, there is higher incidence of diarrhoeal diseases during the months of November, in the short season of rain (18%) and in July (16%) after the big rain season, than other months in Rwanda. The prevalence rate of diarrhoeal diseases in Masaka Health centre in 2010 was 57/1,000 population (5.7).

Table 4.6 shows the proportion of symptoms distributed across the age groups. Among the patients who reported at Masaka health Centre, children under five years old constituted the majority (54%) of symptoms of diarrhoeal diseases patients. Specifically, they reported 60% of watery stools and 61% of fever, 76% of vomiting, and 47% of dehydration. Bloody diarrhoea (watery stools mixed with blood) symptoms were most reported among the age groups 20-29 years and 30-39 years followed by 50-59 years.

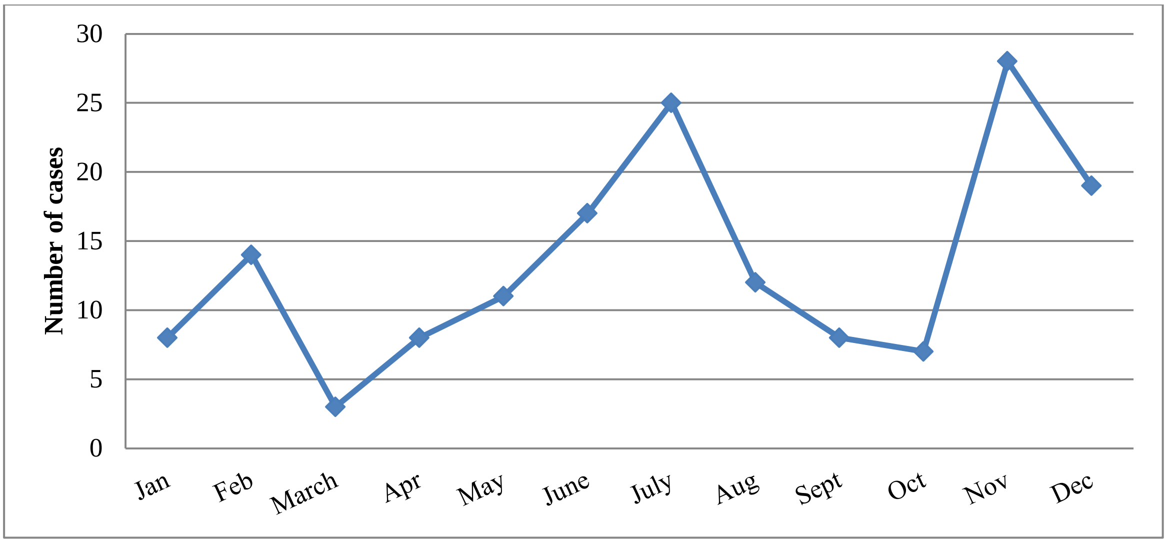


Figure 4.4: Number of diarrhoea cases per month reported to Masaka Health Centre from study communities during 2010

Table 4.6: Distribution of symptoms reported to Masaka Health Centre according to age group

Age group	Fever	Watery stools	Watery stools mixed with blood	Abdominal pain	Vomiting	Dehydration	Nausea	Total	%
<5	48	86	0	16	19	8	0	177	54
5 - 9	3	5	1	2	1	1	1	14	4
10-19	9	15	2	6	1	5	3	41	12
20-29	9	13	4	8	1	3	1	39	12
30-39	3	6	4	4	1	0	1	19	6
40-49	3	6	1	3	1	0	0	14	4
50-59	3	7	3	2	1	0	1	17	5
≥ 60	1	5	0	3	0	0	0	9	3
Total	79	143	15	44	25	17	7	330	100

4.3 KAP on water usage and waterborne diseases in Rusheshe and Ayabaraya communities

Structured questionnaires were administered to women in the households of Rusheshe and Ayabaraya rural communities of Masaka to assess the women's KAP in terms of water usage and waterborne diseases. Only women between 18 and 55 years old were chosen to participate in the interview on KAP about water handling at home and waterborne diseases since women in this age group are predominantly involved in water collection and use. However, returned questionnaires included respondents under 18 years of age who were not included in the study as they would not have been able to provide answers to all questions. Out of 328 questionnaires 324, (193 (n=197) from Rusheshe community and 131 (n=131) from Ayabaraya community), were used in the analysis.

Table 4.7: Summary of the study household demographics in rural areas of Masaka

Demographics	N (%)
Age representation of the respondent (n= 324)	
18-25 years	43 (13)
26-35 years	135 (42)
36-45 years	97 (30)
46-55 years	49 (15)
Educational level of the respondent (n= 324)	
No schooling	46 (14)
Some primary school	208 (64)
Standard 6-9	64 (20)
High school matriculate	6 (2)
Tertiary education	0 (0)
Age of people living in the study households	
< 5 yrs	278 (18)
6-10 yrs	279 (18)
11-18 yrs	301 (19)
> 18 yrs	712 (45)
TOTAL	1570 (100)

4.3.1 Demographic information

Demographics of the study population are indicated in Table 4.7. The respondents were aged between 18 to 55 years. On average the majority of the respondents (42%) were between the ages of 26-35 years. The majority of respondents (64%) had some level of primary schooling as their highest education while only 2% had some secondary education. A total of 1570 people lived in the 324 interviewed households and the average number of people per household was 4.8. In these households, children below 5 years accounted for 18% of the study population (Table 4.7).

4.3.2 Water handling

4.3.2.1 Source of water

The main source of water in the two communities is the Nyabarongo River water. As shown in Table 4.8, more than three quarter of the respondents (78%) indicated that their source of water was the Nyabarongo River while only 16% used tap water. Many of the people in the study areas had to walk long distances to water sources. For 31.5% of the respondents, the river was located between 50 and 100 m and 35.5% walked between 100 and 500 m to the river while for only 2.5% of the respondents, the river was located at less than 50 m to their house. The majority of the people who used tap water, 45 out of 52 (86%) had to travel for more than 500 m to the tap.

Table 4.8: Distance betweenthe study households to water source in rural communities of Masaka (n= 324)

		Water source used n (%)			
		Public tap	Nyabarongo River	Other	Total
Distance to water source	< 50 m	0 (0%)	8 (2.5%)	1 (0.3%)	9 (2.8%)
	50 - 100 m	3 (0.9%)	102 (31.5%)	9 (2.8%)	114 (35.2%)
	100 - 500 m	4 (1.2%)	115 (35.5%)	8 (2.5%)	127 (39.2%)
	> 500 m	45 (13.9%)	29 (9%)	0 (0%)	74 (22.8%)
Total		52 (16.0%)	254 (78.4%)	18 (5.6%)	324 (100.0%)

4.3.2.2 Water storage and treatment

The summary of water storage and treatment practices is shown in Table 4.9. Of all the households investigated, 93% of the respondents used plastic containers for water collection and storage and 67% of respondents indicated that they did not cover their water storage containers. Nearly all the respondents (96%) indicated that they kept their water storage containers indoors. In terms of the method of drawing water from the storage container, the majority of the households (92%) used a mug or a small container to transfer water from the storage container.

Only 9% of all respondents reported cleaning the water storage container daily, while 26% rarely cleaned the storage containers. Fifty five percent (55%) of the respondents cleaned their storage containers using soap and water. Most of the respondents (82%) indicated that they used separate containers for drinking purposes and for cooking, washing hands and cleaning of kitchen utensils. With regards to water treatment before use, 37% of the study households did not treat water before use, 29% added Sûr'Eau (WaterGuard) before using it, while 20% of the respondents indicated filtration with slow Sand Filters (SSF) distributed in the community by World Relief as a treatment method of their drinking water (Table 4.9).

Table 4.9: Water storage practices and treatment used by the study households in rural areas of Masaka (n=324)

Data	**N (%)**
Plastic	302 (93)
Metal	0 (0)
Other	22 (7)
Container storage conditions	
Open	216 (67)
Closed	108 (33)
Water container storage kept	
Outdoors	14 (4)
Indoors	310 (96)
How water is obtained from the storage container	
Mug	297 (92)
Tap	0 (0)
other	27 (8)
Number of times the storage container is cleaned	
Daily	28 (9)
Weekly	74 (23)
Monthly	137 (42)
Rarely or not all	85 (26)
Cleaning storage container with	
Water only	44 (14)
Soap and water	95 (29)
Separate container for drinking water	
Yes	265 (82)
No	59 (18)
Drinking water treatment	
Boiling	46 (14)
Sûr'Eau	92 (29)
No treatment	121 (37)
Other	65 (20)

4.3.3 Sanitation and hygiene related information

Almost all the respondents (97%) indicated that they have a toilet at home. The respondents were also asked the importance of having a latrine, the majority of the respondents (77%) indicated that they use a latrine for privacy; while 39% expressed that the latrine is important to prevent them from getting diseases. With regards to hand washing practices, almost all the respondents (97%) indicated that they washed hands before eating, 43% of the respondents washed hands after using a toilet, while only 20% of the respondents washed hands before they prepared food (Table 4.10). According to the study results, nearly 12% of respondents washed hands using water only. Regarding the importance of washing hands, most of the respondents (80%) indicated that they washed hands to be clean, 46% of the respondents said washing hands is important in preventing diseases while 30% washed hands to be healthy (Table 4.10).

Table 4.10: Summary of hygiene and sanitation practices in the study households in rural areas of Masaka (n=324)

Data	N (%)
Presence of toilet at the household	
Yes	315 (97)
No	9 (3)
Reasons of having a toilet at home**	
To keep the village clean	108 (67)
To keep the village free from odour	156 (52)
To prevent disease	125 (39)
Privacy	248 (77)
Hand washing practices**	
Before eating	315 (97)
Before food preparation	65 (20)
After using a toilet	140 (43)
After waking up in the morning	93 (29)
After cleaning the baby's buttocks	100 (31)
Wash hands with	
Soap and water	283 (87)
Ash and water	2 (1)
Plain water	38 (12)
Sand and water	1 (0)
Importance of washing hands **	
To be clean	260 (80)
To prevent diseases	148 (46)
To be healthy	96 (30)

*Numbers/ Percentages may not add up to the total number due to missing data
** Not mutually exclusive

4.3.4 Knowledge, practices and attitudes regarding waterborne diseases

4.3.4.1 Awareness of waterborne diseases by the respondents

During this study, participating women were asked about the knowledge of waterborne diseases, their causes and their practices to prevent them. The most common waterborne diseases that were listed by the respondents were diarrhoea (77%), cholera (61%) and dysentery (40%). Six percent (6%) of the respondents indicated that they did not know any disease caused by dirty water (Figure 4.5).

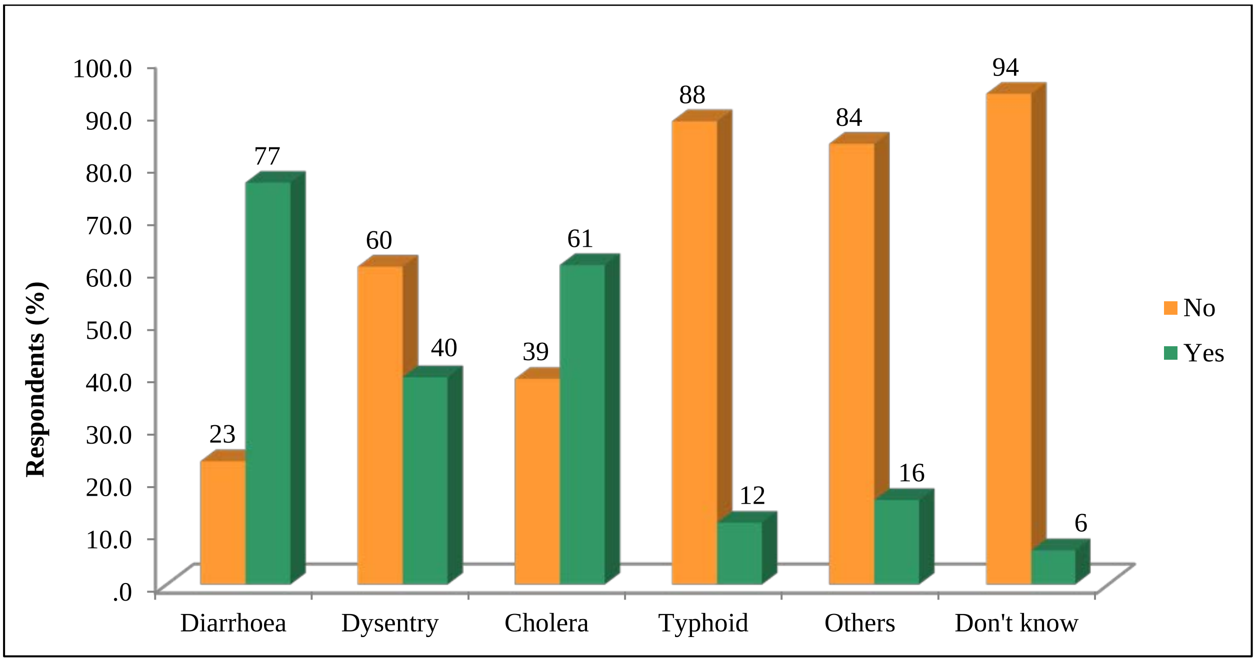


Figure 4.5: Awareness of waterborne diseases by the respondents

During the interview it was found out that a total of 112 households in the two communities had people who suffered from diarrhoea in six months prior to the interview. Most (75/112; 67%) were children under the age of 5 years.

4.3.4.2 Knowledge and Practices associated with diarrhoeal diseases

In terms of the possible causes of diarrhoea, 60% of the respondents identified contaminated water as the possible cause while 9% thought it was caused by eating stale food. Other causes identified were dirty hands and surroundings (Table 4.11). During the interview, respondents were asked if they had experienced symptoms of waterborne diseases during six months prior to the interview. A total of 111 (34%) of the respondents indicated that they experienced diarrhoea symptoms. Twenty eight percent (28%) of the respondents reported that they had watery stool, while 3% indicated that they had bloody stools. Of the respondents who had diarrhoea symptoms, only 55% sought treatment at the clinic, while the others (39%) preferred to treat themselves at home or use a traditional healer (6%) (Table 4.11).

Table 4.11: Descriptive data on KAP on waterborne diseases in the study households (n=324)

Data	N (%)
Experience of diarrhoea in household	112 (35)
Causes of diarrhoea episodes (N=112)	
Contaminated water	67 (60)
Eating stale food	10 (9)
Dirty hands	12 (11)
Dirty surrounding	21 (18)
Religious belief	2 (2)
Symptoms experienced in the last 6 months:**	
Watery stool	89 (28)
Bloody stool	9 (3)
Vomiting	27(8)
More than 4 loose stool within 24 hours	52 (16)
Households which reported diarrhoea the symptoms to the clinic (N=112)	62 (55)
Households which treated diarrhoea the symptoms at home	43 (39)
Households which used traditional healers for diarrhoea the symptoms treatment	7(6)
Diarrhoea prevention practices at home **	
Treat drinking water	203 (63)
Keep water in a clean and closed container	108 (33)
Wash hands	148 (46)
Use and clean toilet	124 (38)
What the respondent think should be done to prevent diarrhoea	
Water provision	209 (65)
Public hygiene	45 (14)
Health Education	67 (21)
Nothing	3 (1)
Respondents with knowledge on diarrhoea treatment at home	102 (31)
Respondents without knowledge on diarrhoea treatment at home	222 (69)

*Numbers/ Percentages may not add up to the total number due to missing data
** Not mutually exclusive

When asked about prevention of diarrhoea, 63% of the respondents indicated that they treated their drinking water and 46% washed their hands to prevent diarrhoea (Table 4.11). Nearly two thirds (65%) of the respondents believe that diarrhoeal diseases may be prevented by having treated water supplied to the communities by the government, 21% indicated public education as a possible way of diarrhoea prevention (Table 4.11). Women were asked if they knew how to treat diarrhoea at home. Most of the respondents (69%) had no idea about treating diarrhoea at home. However, 31% of the respondents indicated that a mixture of water, sugar and salt (Sugar-Salt Solution), coupled with water and food could treat diarrhoea at home and prevent dehydration in children (Table 4.11).

4.3.5 Bivariate analysis

Pearson's chi-square tests were performed to determine whether water handling practices, hand washing practices, knowledge of waterborne diseases and their prevention was dependent on educational level of respondents. As presented in Table 4.12, the results showed that people who went to school were more likely to cover their storage containers than those who didn't go to school. No significant associations were identified for storage container cleaning practices and level of education of the respondent. Approximately 32% participants who attended primary and 31.4% who went to high school used Sûr'Eau as a method of drinking water treatment compared with 6.5% of the respondents who did not go to school ($p < 0.05$).

The results in Table 4.13 show that within the sample, 22.6 % of all people who washed hands after using a toilet had primary school level, 21.4% had high school level, while 6.5% didn't go to school. The frequencies of people, who washed hands after using a toilet and after cleaning the baby's buttocks, were significantly higher with people who went to school ($p < 0.05$). Significant associations were found between the awareness of the importance of washing hands and level of education ($p < 0.05$). Similarly, the results indicated that awareness of waterborne diseases and reporting the experienced symptoms to the clinic were significantly associated with the level of education of the respondent ($p < 0.05$). The frequencies of awareness of diarrhoea treatment at home were approximately 2 times higher in respondents who went to primary and high school than in those who didn't go to school.

Table 4.12: Water handling practices among participants stratified by level of education (n = 324)

Water handling practices		**Educational level (n = 324)**			**p-value**
		No schooling	**Primary school**	**High school**	
Material of Water storage container	Plastic	37 (80.4)	197 (94.7)	66 (94.3)	**0.003**
	Clay pot	9 (19.6)	11 (5.3)	4 (5.7)	
Condition of storage container	Not covered	37(80.4)	130 (62.5)	49 (70)	0.05
	Covered	9 (19.6)	78 (37.5)	21 (30)	
How water is obtained from the storage container	Mug	42 (91.3)	193 (92.8)	62(88.6)	0.54
	Pour	4 (8.7)	15 (7.2)	8 (11.4)	
How often the storage container is cleaned	Daily	3 (6.52)	21(10.10)	4 (5.71)	0.14
	Weekly	5 (10.87)	52 (25.00)	17 (24.29)	
	Monthly	19 (41.30)	86 (41.35)	32 (45.71)	
	Rarely	19 (41.30)	49 (23.56)	17 (24.29)	
What used to clean the storage container	Water only	3 (6.5)	21 (10.1)	4 (5.7)	0.137
	Soap and water	5 (10.9)	52 (25)	17 (24.3)	
	Sand and water	19 (41.3)	86 (41.4)	32 (45.7)	
	other	19 (41.3)	49 (23.6)	17 (24.3)	
Method of drinking water treatment	Boiling	2 (4.4)	36 (17.3)	8 (11.4)	**p<.05**
	Sûr'eau	3 (6.5)	67 (32.2)	22 (31.4)	
	No treatment	28 (60.9)	68 (32.7)	25 (35.7)	
	Filtration (SSF)	13 (28.3)	37 (17.8)	15 (21.4)	

p-value from Pearson chi squared test
All values in bold print are significant ($p < 0.05$)

Table 4.13: Frequencies of hand washing practices and awareness of waterborne diseases stratified by level of education

Characteristics	Educational level (n=324)			p-value
	No schooling	**Primary school**	**High school**	
Hand washing practices**				
Washing hands before food preparation	3 (6.5)	47 (22.6)	15 (21.4)	0.05
Washing hands after using a toilet	3 (6.5)	99 (47.6)	38 (54.3)	***p*<.05**
Washing hands after waking up	16 (34.8)	56 (26.9)	21 (30)	0.55
Washing hands after cleaning the baby's buttocks	7 (15.2)	67 (32.21)	26 (37.1)	**0.03**
Importance of washing hands **				
Wash hands to be clean	39 (84.8)	166 (79.8)	55 (78.6)	0.69
Wash hands to prevent diseases	6 (13)	103 (49.5)	39 (55.7)	***p*<.05**
Wash hands to be healthy	2 (4.4)	72 (34.6)	22 (31.4)	***p*<.05**
Awareness of diseases	36 (78.6)	198 (95.2)	69 (98.6)	***p*<.05**
Symptoms experienced reported to the clinic	2 (22.2)	47 (62.7)	12 (44.4)	**0.032**
Knows how to treat diarrhoeal at home	7 (15.2)	67 (32.21)	28 (40)	**0.02**

p-value from Pearson chi squared test
All values in bold print are significant ($p < 0.05$)
*Numbers/ Percentages may not add up to the total number due to missing data
** Not mutually exclusive

Further, the Pearson's chi square test results evaluated whether experience of diarrhoea in the households was dependent on hand washing practices. Table 4.14 shows that the frequency of diarrhoea were significantly higher among people who did not wash hands before food preparation (*p* = 002) and after using a toilet (*p* = 0.007) than among those who did. Within the sample, 82% of all people who had diarrhoea did not wash hands after waking up. No significant associations were observed for diarrhoea experience and the other hand washing practices.

Table 4.14: Bivariate analysis using the chi-squared test to evaluate the association of diarrhoea experience in the households with hand washing practices

Characteristics	Experience of diarrhoea in households (n=112) N (%)	p-value
Hand washing Practices **		
Washing hands before eating	111 (99)	.133
Washing hands before food preparation	12 (11)	**.002**
Washing hands after using a toilet	37 (33)	**.007**
Wash hands after waking up	20 (18)	**.002**
Wash hands after cleaning the baby's buttocks	33 (29)	.692
Wash hands with*		.846
soap and water	98 (88)	
Ash and water	1(1)	
Plain water	11 (10)	
Wash hands to be clean	84 (75)	.085
Wash hands to prevent disease	46 (41)	.226
Wash hands to be healthy	29 (26)	.284

All values in bold print are significant ($p < 0.05$)
*Numbers / percentages may not add up to the total due to missing data
** Not mutually exclusive

4.3.6 Multiple logistic regression models

In this study, associations of educational level, source of water, knowledge of waterborne diseases, water handling practices variables with symptoms of diarrhoea were examined using multivariate logistic regression. Stepwise logistic regression models indicated that frequency of water storage container cleaning and importance of hand washing practices were significant covariates in the logistic models and it was decided *a priori* to include age as a covariate. Multivariate logistic models using diarrhoea experience as the dependent variable and educational level as the independent variable showed a significant association (*p* =0.04) between levels of schooling and symptoms of diarrhoea (Table 4.15). No significant association was observed between respondents who had knowledge of waterborne diseases and diarrhoea experienced (adj. OR = 1.01; CI: 0.36 - 2.87; *p* = 0.98 (Table 4.15)).

Respondents who used Nyabarongo River as source of water were more likely to have symptoms of diarrhoea (adj. OR = 5.35; CI: 2.12 - 14.46; $p < 0.05$).

Table 4.15: Association of educational level and awareness of waterborne diseases with diarrhoea experience in the study households

Variables	Diarrhoea		
	Adj. OR	**95%CI**	**p-value**
Educational level			
No schooling	1.00		
Primary school	0.35	0.15 - 0.85	0.02
Some high school	0.36	0.14 - 0.96	0.04
Awareness of diarrhoea diseases			
No	1.00		
Yes	1.01	0.36 – 2.87	0.98
Water source			
Tap water	1.00		
Nyabarongo River	5.35	2.12 - 14.46	***p*<0.05**
Other	1.54	0.32 - 7.30	0.59

Logistic regression models adjusted for age and how often the water storage container was washed (daily, weekly, monthly, rarely or not at all)

Respondents with primary school education only and those with high school education were significantly associated with washing hands after using a toilet (adj. OR= 5.24, CI 1.42-19.38, $p = 0.01$ and OR = 7.15, CI = 1.79 -28.62, $p = 0.01$, respectively). No significant associations were identified for each of educational levels and washing hands before food preparation. Subjects who had knowledge of waterborne diseases were 3.5 times more likely to wash their hands after using a toilet than those that did not (Unadj. OR= 3.47; CI: 1.14 – 10.52; $p = 0.03$ (not shown in tables); however, after adjustment with age, water source and importance of washing hands, there was no significant association (OR= 0.32; CI: 0.09 – 1.17; $p = 0.08$). Awareness of waterborne diseases was significantly associated with washing hands before food preparation (adj. OR =3.65; CI: 1.32 - 10.08; $p < 0.05$ (Table 4.16)).

Table 4.16: Association of educational level and awareness of waterborne disease with hand washing practices

Variables	Hand washing after using a toilet			Hand washing before preparing food		
	Adj. OR	95% CI	P-value	Adj. OR	95% CI	P-value
Educational level						
No schooling	1.00			1.00		
Primary school	5.24	1.42 – 19.38	0.01	2.33	0.61 – 8.96	0.23
Some high school	7.15	1.79. – 28.62	0.01	2.64	0.61 – 11.36	0.19
Awareness of waterborne diseases						
No	1.00			1.00		
Yes	0.32	0.09 -1.17	0.08	**3.65**	**1.32 -10.08**	**0.01**

Logistic regression models adjusted for age, water source used, importance of washing hands

This chapter presented the findings from the three sets of data generated namely bacterial results of water used in the study areas; prevalence of diarrhoeal diseases and the women KAP regarding water usage and waterborne diseases in the study areas. Chapter 5 discusses in detail the significance of these findings.

CHAPTER 5: DISCUSSION

Access to safe water and sanitation facilities as well as knowledge of proper hygiene practices, can reduce the risk of illness and death from waterborne diseases (CDC, 2010). Diarrhoeal diseases are caused by ingestion of water contaminated with faecal pathogens contained in human or animal excreta. This study investigated the microbiological water quality of water used by rural areas of Masaka, women's knowledge, attitudes and practices (KAP) on water handling and its link to the prevalence of waterborne diseases. The results of this study showed that both water source and household water samples had bacterial counts which exceeded the recommended values of the Rwandan and World Health Organization (WHO) guidelines for water intended for household purposes. Slow Sand Filter (SSF) and Sûr'Eau as household based treatment methods, significantly reduced total and faecal coliforms counts in river water ($p < 0.05$). Out of 2814 clinic records reviewed from the study areas, the prevalence of diarrhoeal diseases was 160 (57/1000) of which 56% were children under five years. Furthermore, this study indicated that the Nyabarongo River used as a primary water source was significantly associated with diarrhoeal episodes in the study households. Participants who used Nyabarongo River as their water source were more likely to get diarrhoeal symptoms than those who used other water sources (Adj. OR 5.35, CI: 2.12-14.46; $p < 0.05$). Similarly, educational level and hand washing practices before eating and after using a toilet were significantly associated with experience of diarrhoeal diseases in the study households (Table 4.13 and Table 4.14).

Microbiological quality of the primary water source used in both communities was assessed using total coliform and faecal coliform bacteria as indicators. Coliforms are the most common group of indicator organisms used in water quality monitoring. These organisms are representative of bacteria normally present in the intestinal tract of mammals including human. The presence of these bacteria in water samples was a general guideline to indicate the presence of potential faecal contamination and the presence of possible pathogenic microorganisms and to determine the health risk to the consumers (DWAF, 1996; Alotaibi, 2009). According to the WHO and Rwandan guideline values for bacteriological parameters, the total and faecal coliform bacteria should be 0 cfu/100 ml in water intended for drinking. In this study the total coliform and faecal coliform counts for Nyabarongo River, exceeded the WHO and Rwandan recommended drinking water guideline value (Table 4.1). These results are supported by previous studies conducted in rural areas (Potgieter, 2007; Abera et al., 2011; Chigor et al., 2011). These studies found that microbiological parameters counts for river water in rural areas were above the permissible limits and were a potential hazard to public health (Chigor, 2011). However, WHO recognizes that these targets would be difficult to achieve in some cases, especially in rural communities with untreated water supplies, and recommends that in these settings, the guidelines values should be seen as goals for the future, rather than an immediate requirement (UNICEF**,** 2008a).The results indicated that there were no statistical significant differences of means for total coliform and faecal coliform mean counts (p = 0.51 (TC) and p = 0.78 (FC) respectively), between samples taken directly from different sampling sections on Nyabarongo River. This finding differs from a previous study carried out on Danube River country which showed lower bacterial pollution on upstream of the River and higher levels of faecal pollution in the middle part and downstream of the River (Kavka et al., 2002).

Slow Sand Filter (SSF) and chlorination are two of the most common, low-cost and easily maintained water treatment systems for surface waters in developing countries (WHO, 2004). One previous study conducted in Haiti, showed that SSF effectively removed microbial pathogens by 98.5% and reduced turbidity of the influent from 6.2 NTU to 0.9 NTU in the effluent. The SSF's effectiveness in removing microbial pathogens from the water was based on the *E. coli* colony counts from the effluent and 80% of the water samples out of the SSF had zero colonies in the sample (Baker and Duke, 2006). In the present study, SSF showed a significant reduction of total coliform and faecal coliform colonies with an overall average of 96% for both parameters. However bacterial removal was not complete since the findings of this study showed that the mean counts of both total and faecal coliform bacteria exceeded the WHO and Rwandan recommended guideline value of 0 cfu/ 100ml (WHO, 2006; RBS, 2010). The average levels for filtered water were 284 cfu/100ml for total coliforms and 75 cfu/100ml for faecal coliforms (Table 4.2). It is important to note that none of the households treated the water with chlorine after filtering and they poured the source water directly into the filter, not allowing time for sedimentation or settling. This indicated lack of knowledge regarding disinfecting the water post-filtering and safe water storage practices.

The present study showed a significant reduction of total coliform and faecal coliform counts after treating water with Sûr'Eau. Bacterial removal after using Sûr'Eau averaged 95% for total coliform and 93% for faecal coliform. However, the average bacterial concentrations in

Sûr'Eau treated water were still higher than the recommended value set by WHO (2006) and Rwanda (RBS, 2010). Only 2 (25%) of all samples for total coliforms and 3 (37%) for faecal coliforms, tested less than 1 cfu/ 100 ml after the use of Sûr'Eau (Table 4.3). Previous studies have shown that sodium hypochlorite solutions effectively reduced the numbers of indicator microorganisms to undetectable counts limit in drinking water (Luby et al., 2004, Firth et al., 2009). However, all these studies tested samples with relatively low turbid water (<32 NTU). Potgieter (2007), in a study carried out in rural households of South Africa, showed that *E. coli* were inactivated by 1% sodium hypochlorite solution within 60 minutes of exposure in river water. Highly turbid water requires longer chlorine contact times and the addition of a double dose of hypochlorite solution, but disinfection may not be effective enough against pathogens within flocs or particles (WHO, 2004). Therefore, a pre-treatment is needed in order to remove large particles before adding Sûr'Eau (Nath et al., 2006, UNICEF**,** 2008b).

The observed turbidity mean values for both filtered water and Sûr'Eau treated water in the study communities were well above the recommended upper limit guideline value of 5 NTU for drinking water (WHO, 2008 (Table 4.2). The results of this study showed no apparent correlation between turbidity and bacterial counts (TC and FC). This could be attributed to the fact that turbidity is caused not only by the presence of microorganisms in water, but also of particulate matter, such as clay, silt and colloidal particles (WHO, 2008).

The high counts of total and faecal coliform bacteria per 100 ml obtained from the water samples of the river and household revealed that the microbiological quality of the water sources used was poor, unsafe and not acceptable for human consumption and could potentially increase the health risk associated with waterborne diseases (Potgieter, 2007).The water quality results agree with the clinic data showing that the prevalence of diarrhoeal diseases in the study areas was high among people who used water from Nyabarongo River. Incidences of waterborne diseases including diarrhoea are one of the basic problems in Rwanda and particularly in the study areas. A study conducted in Nakuru, Kenya, showed the prevalence of waterborne diseases of 56/1000 population (Chabalala and Mamo, 2001). The present study indicated that the prevalence of waterborne diseases was 57/1000 (5.7%) population, which is lower compared to other studies conducted in rural areas of developing countries (Ahmed et al., 2008; Gul et al., 2011). In these studies, the prevalence was respectively 25.2% and 27% in Ahmed et al. (2008) and Gul et al. (2011). It was revealed that among the patients, children under the age of five (56%) were more prone to diarrhoeal diseases (Table 4.6). These results agree with other studies carried out in rural areas which showed a higher prevalence of diarrhoeal diseases in children under-five than in other age groups (Ahmed et al., 2008; Ogutonke et al., 2009). In these studies, the prevalence of diarrhoeal diseases was respectively 25.2% and 35.5%. Higher occurrence of waterborne diseases among children, especially under- fives, may be linked to increased susceptibility of children to infections due to their low immunity (Ogutonke et al., 2009). This might also be due to the fact that knowledge on child healthcare is inadequate among the caregivers in rural communities (Rana, 2009). In this study, logistic regression analyses showed that diarrhoea experienced in the study households, was significantly associated with women's educational levels ($p<0.05$). This finding agrees with previous studies which found a positive correlation between the prevalence of diarrhoea in children and the level of the mother's education (Rana, 2009; Onyago and Angienda, 2010; Arif and Naheed, 2012).

In the present study we could not directly relate diarrhoeal episodes to waterborne diseases. This could be attributed to the fact that many of the signs and symptoms of waterborne diseases and the health effects of water pollution are non-specific and often mimic more common medical conditions and disorders (Meinhardt, 2006). However, in order to guide optimal case management, and for the purposes of epidemiological tracking, diarrhoeal episodes are diagnosed according to symptoms into one of the following two categories: acute watery diarrhoea or non-bloody diarrhoea, dysentery or bloody diarrhoea (Ahs et al., 2010). The most prevalent diarrhoeal symptom observed in the present study, was watery stools (89%) and bloody diarrhoea contributed 11% of all the symptoms reported at the clinic. According to WHO (2010), 50% of the world cases of diarrhoea present with watery diarrhoea and approximately 35% are chronic diarrhoea while 15% form dysenteric diarrhoea of the 1,500 million episodes of diarrhoea in children under the age of 5 years that results in 4 million deaths.

Evidence shows that the educational status and health outcomes are strongly associated. It might be anticipated that persons who attended schools are aware of susceptibility of diseases thereby more likely to pursue preventive measures (Hasuizume et al., 2008). Rana (2009) found that prevalence of waterborne diseases was significantly higher among illiterate women caregivers in rural Bangladesh ($p < 0.001$). A recent study in Pakistan by Arif and Naheed (2012), found no significant relationship between a mother's age and the occurrence of diarrhoea among under-five children; however, their results showed that the prevalence of diarrhoea decreased with higher education. These studies are in agreement with our findings. In the present study, the demographic characteristics considered were level of education and age of the participants in the households. No significant relationship was found between the women's age and the occurrence of diarrhoeal diseases in the study households. However, bivariate Pearson chi square tests showed that women who went to school were more likely to use Sûr'Eau as a method of drinking water treatment ($p < 0.05$). The number of people who washed hands after using a toilet was significantly higher among people who attended school ($p < 0.05$). Similarly, the awareness of the importance of washing hands, awareness of waterborne diseases and reporting of symptoms to the clinic were significantly associated with the level of education of the respondent ($p < 0.05$). This suggests that level of education plays a major role in water handling practices and waterborne diseases preventions practices in rural communities and the results of this study as well as other studies conducted in rural areas confirmed this (Young at al., 2007; Rana, 2009).

Qureshi et al. (2011) linked the prevalence of waterborne diseases with the water source. Similarly, this study found significant association between Nyabarongo River and experienced diarrhoeal symptoms in the study households (adj. OR =5.35; CI: 2.12 -14.46; $p < 0.05$). Nyabarongo River was the most popular primary source of water in the study areas (78.4%). Additionally this study indicated that experience of diarrhoeal diseases in the households was significantly more frequent among people who did not wash hands before food preparation and after using a toilet than among those who washed hands (p = 0.002 and 0.007, respectively). This result is supported by other studies that found that hand washing practices at critical times: after defecating, after cleaning a child's buttocks and before eating or preparing food were shown to be effective in the reduction of diarrheal diseases (Khale and Dyalchand, 2008; Cairncross et al., 2010 and Luby et al., 2011).

Inadequate or no treatment of drinking water remains a problem in rural communities. More than a quarter of the study households (37%) did not use any treatment before consuming their water. Several studies have reported that inadequate storage could result in an increase in numbers of some microorganisms such as heterotrophic bacteria and total coliform over time (Sobsey, 2002; Seino et al., 2007). Earlier studies by Dunker (2001) and Nala and co-workers (2003) have shown that open water storage containers were more at risk of being contaminated by human and animals than containers which were covered. The results of this study showed that the majority of the respondents (67%) did not cover the water storage containers which suggested that water in these households was at risk of getting contaminated. In this study, only 9% of the households reported cleaning their storage containers daily. The remaining 91% of the households cleaned their water storage containers after a week or a month or rarely cleaned them at all (Table 4.10). Consequently, biofilm formation inside the household's water storage containers could, due to improper cleaning practices, facilitate the survival and the growth of potential pathogenic disease causing microorganisms (Potgieter, 2007). A study however, looking at the impact of tank material on water quality in household water storage systems in Bolivia indicated that cleaning frequency may contribute to microbial water quality. Although there was no statistically significant association, storage containers that were reported to be cleaned 3 or more times per year have less *E. coli* than containers cleaned less frequently (p = 0.102) (Schafer, 2010).

The majority of households (92%) used a mug to draw water from the storage container. Water must be stored and drawn in a safe manner, otherwise water may be contaminated. The latter happens when there is a communal mug on top of the covered container (Tambekar et al., 2008). When drawing water from the storage container, adults and children dip this mug into water and may then touch the water with dirty hands. In this way, bacteriological quality of drinking water may significantly decline at these households (Sobsey, 2002). Proper lid for the storage container and daily cleaning of the container may prevent the contamination of household stored water (Tambekar et al., 2008). However, in this study 67% of all the respondents indicated that they did not cover water storage containers and only 9% washed their storage containers (Table 4.9). These practices indicated limited knowledge and education of the households on water storage practices for prevention of household water contamination.

Ignorance on waterborne diseases may also play an important role in health awareness in a household (Crump et al., 2005). This study reveals that the awareness of waterborne diseases is relatively high, as can be seen in Figure 4.5. As far as knowledge of diarrhoea/gastroenteritis and cholera go, most of the people associate the diseases mainly to contaminated drinking water (76.5%). This study found a significant association between knowledge of waterborne diseases and level of education of the respondent ($p < 0.05$). Awareness of waterborne diseases of women impacted on hand washing practices. Those who had knowledge of waterborne diseases were more likely to wash hands, especially before preparing food (Adj. OR = 3.65; CI: 1.32 – 10.08; p = 0.01) as compared to those who did not have knowledge of waterborne diseases. Although not statistically significant (p =

0.08), the frequency of women who washed hands after using a toilet was higher in women who were aware of waterborne diseases than in those who were not.

Some health measures to prevent diseases can be undertaken by the community as a whole; these include water source protection, proper disposal of solid waste and excreta, wastewater drainage, controlling animal rearing and market hygiene. In addition to diarrhoea prevention practices at the household level, home treatment has been recommended in order to manage diarrhoea cases, thus reducing the burden of childhood diarrhoea (UNICEF/WHO, 2009). Sixty seven percent of the respondents suggested that provision of potable water could reduce the prevalence of diarrhoea in the household, while 21% thought health education on water handling practices could contribute to the prevention of diarrhoeal diseases.

Home treatment of diarrhoea is an essential part of the correct management of acute diarrhoea. The treatment package focuses on two main elements, as laid out by the UNICEF and WHO: Fluid replacement to prevent dehydration and Zinc treatment. Oral rehydration therapy is the cornerstone of fluid replacement. New elements of this approach include low-osmolarity Oral Rehydration Solution (ORS), which are more effective at replacing fluids than the previous ORS formulation, and zinc treatment, which decreases diarrhoea severity and duration. Important additional components of the package are continued feeding, including breastfeeding, during the diarrheal episode and use of appropriate fluids available in the home such as sugar-salt solution if ORS are not available (UNICEF/WHO, 2009).

In developing countries, introduction of oral rehydration therapy (ORT) has led to a marked reduction in deaths caused by diarrhoea and cholera among children (Bloomfield et al., 2009). Primary caregivers, especially women, in developing countries need to know how to prepare the home made fluids and to use them properly. The results of the present study (Table 4.11) indicated that 69% of the respondents didn’t know how to treat diarrhoea at home which may contribute to the related high child mortality rates (23%) from diarrhoea in Rwanda (UNICEF, 2010).

WHO estimates that 94% of diarrheal cases are preventable through modifications to the environment including interventions to increase availability of clean water and to improve sanitation and hygiene (WHO, 2007). In addition to water and sanitation policy, Rwanda has a target of providing safe water and sanitation to all Rwandans by 2020. The importance of adequate water supply and sanitation services as drivers for public health is fully acknowledged in Rwanda's flagship policy documents and political goals (MININFRA, 2010). Based on the results of the questionnaire survey of this study among the residents of rural Masaka, this study evaluated implementation of this water services in terms of water supply in rural areas. The Rwandan target for rural water supply coverage is to raise rural water supply coverage to 85% by 2012 and to 100% by 2020. However, this study showed that only 16% of the rural population under study had access to an improved water source (Table 4.9).

In addition, the water and sanitation policy states that the target for reasonable access to an improved water source in rural areas is 0 m to 500 m from the water collection point to the household (MINITERE, 2004). In rural areas of Rwanda, water access is defined in terms of being within 500 meters; however, the average distance to a water point is more than 500 meters for all the provinces outside Kigali (Sano, 2007). In this study, the majority of the people who used the only improved water source, tap water (86%), had to walk more than 500 m to the tap. A study evaluating water policy implementation in rural areas by Chacha, et al. (2009) showed that the majority of those living in rural areas spend more time travelling to water sources than in urban areas. Another study carried out in a rural area in the North Eastern region of South Africa also found that accessibility to safe water quality through a piped distribution system and communal taps did not fall within the parameters of safe-water provision in terms of distance from household to water source (Jagals, 2006). However, the South African target for reasonable access to a water source is 0 m to 200 m from the place of dwelling (DWAF, 1994) which is shorter than Rwandan policy. The basic water policy for both South Africa and Rwanda is to guarantee the provision of basic water (25 litres per person per day) for domestic usage, health and sanitation (DWAF, 1994; MININFRA, 2010). However, based on the information gathered during this study, we believe that the majority of the people residing in our study areas don't even have access to safe water let alone having 25 litres.

There have been many studies in developing countries investigating the microbiological quality of drinking water and water handling practices that may contribute to water contamination at the household level (Quick et al., 2004; Potgieter, 2007; Tambekar et al., 2008; Abera et al., 2011; Chigor et al., 2011). Others evaluated the association between water quality and the pattern of waterborne diseases (Oguntoke et al., 2009; Qureshi et al., 2011). Generally the findings of these studies provide adequate support for the level of water contamination of untreated water source and associations between the occurrence of diarrhoeal diseases, water handling and hand washing practices seen in our study. While this study has produced interesting findings, there were a number of limitations that need to be acknowledged. The first and perhaps the most important is the small number of water samples (n=35). More than thirty five samples can and should be used to elicit the necessary information. However our sample allowed a large, wide-area survey and a comparison with other studies. In this study, water sample collection periods were different i.e. River water samples collection was done in January while household water samples were collected during July, which may affect the results of SSF and Sûr'Eau effectiveness in household water treatment. However, as the seasons don't change considerably and it rains the whole year in Rwanda, the effect might be minimal.

Few studies have documented the effectiveness of SSF and Sûr'Eau in household water treatment (Baker and Duke, 2006; Fitzpatrick et al., 2008) and to our knowledge, this was the first to do so for highly turbid surface water in rural areas of Rwanda. Inadequate knowledge of water treatment as a means to diarrhoea prevention, combined with unhygienic storage and handling of water aggravates the risk of water contamination in the home regardless of quality at the water source (Sobsey, 2003). Future research should focus on a combined system of particle removal and disinfection for effectively treating the highly turbid and microbiologically contaminated water from the Nyabarongo River water being used for household purposes in rural areas of Masaka.

Public awareness regarding the significance of water usage at the point of use as well as hand washing practices and effects on human health are also important and recommended. An integrated approach incorporating policies, plans and activities that safe water provision, health education regarding water handling practices aimed at preventing or minimizing the risk of contaminating drinking water and therefore contraction of waterborne diseases could be the starting point for rural areas of Masaka. The following chapter includes the conclusions of the study, recommendations and future studies.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

To our knowledge this is the first water and sanitation study to be conducted in rural communities of Masaka Sector of Kicukiro District in Rwanda. The results obtained in this study may be used to extrapolate the current scenario in rural communities on the African continent with similar environmental conditions. The microbiological water quality of Nyabarongo River in Masaka was assessed to determine the effectiveness of water treatment methods used at the household level. The prevalence of diarrhoeal diseases was determined to know the status of health in this study area as no data on the prevalence of these diseases in Masaka, in the vicinity of Nyabarongo River is available that could indicate the health status of the population. Further the women's KAP was assessed determine the link to the occurrence of diarrhoeal symptoms in the households. All three objectives as outlined in Chapter 1 have been achieved and important findings from the results will be highlighted in this chapter.

Microbiological assessment of the raw water from Nyabarongo River used by the study households indicated that this water had unacceptable high counts for total coliform bacteria and faecal coliform bacteria according to the recommended WHO and Rwandan guidelines for drinking water and was unsafe for human consumption and could increase the health risk associated with waterborne diseases. The river water had significantly higher counts of coliform bacteria than the household water after treating it ($p < 0.05$). However bacterial removal was not complete since the findings of this study show that the mean counts of both total and faecal coliform bacteria at the household level still exceeded the WHO and Rwandan recommended guideline value. The effectiveness of point-of-use water treatment depends on the degree to which the users prioritise treated drinking water. The results of this study are indicating that although the communities are provided with Sûr'Eau and SSF for treating water at the household level, the water is not necessarily microbiologically acceptable or safe to drink as the general perception is. This suggests that the use of Sûr'Eau alone or SSF alone as treatment methods is not effective as the removal of bacteria in water was not complete.

In this study the effectiveness of SSF and Sûr'Eau treatment methods was not assessed as a combined treatment method for water with high turbidity because the study communities did not used each as a single treatment method. The main concern of these communities was lack of knowledge with regards to water treatment practices and their importance in diarrhoeal diseases prevention. These findings could have implications for future studies, where a combined system will be assessed for particle removal and disinfection for effectively treating the highly turbid and microbiologically contaminated water.

Of all the conditions on the patients seen in the two Masaka Health centre, 5.7% [57/1000 population] were diarrhoeal diseases. The majority of patients were children under the age of five (56%). The proportion of these diseases was high and these are actually preventable diseases. This is an indication that there are poor water and sanitation facilities in the study areas. Poor health promotion and personal hygienic behaviour is a major contributing factor as well.

The results obtained in this study showed that 67% of the respondents did not cover the water storage containers and the majority of them used a mug a method of drawing water from the storage containers. Implications are that these practices may contribute to the faecal contamination. However, awareness of diseases related to use contaminated water among the respondents was quite high. The practice of hand washing before food preparation and after using a toilet was low among the study population. The results of the present study indicated that the majority of the respondents didn't know how to treat diarrhoea at home using Oral Rehydration Solution. These results indicated limited knowledge in the study areas, regarding water storage practices and hand washing practices for prevention of household water contamination which highlights the need of proper education of rural community on the benefits of water storage and hand washing practices.

The results of this study indicated that the frequency of diarrhoea were significantly associated with people who did not wash hands before food preparation and after using a toilet ($p < 0.05$). Similarly respondents who used Nyabarongo River as source of water were more likely to have symptoms of diarrhoea ($p < 0.05$) than who used other water sources. This leads to the realisation that the use of Nyabarongo River, water handling practices and washing hands practices, should be linked to the occurrence of diarrhoeal diseases in our study areas.

Based on the information and experiences gathered during field visits and during analysis data, the following recommendations are made:

- Safe potable water sources should be provided to improve the welfare of residents of Masaka rural areas and to reduce the prevalence of waterborne diseases in the areas.
- The effectiveness of point-of-use water treatment depends on the degree to which the users prioritise treated drinking water. Therefore, education is a fundamental precursor to any such intervention. If the users understand and act upon a perceived health threat from contaminated drinking water, then the filters can provide an effective means for the users to protect themselves. This requires adequate information on the relative threats of drinking water in the community, perhaps through a health education programme.
- Although people know water can be contaminated and can have effects on their health, their knowledge on how some of their actions could contribute to the faecal contamination of drinking water at the point-of-use is limited. There is a need to educate the public on efficient water use practices and the intensification of educational awareness as to how to handle and locally treat water for domestic use.
- Water with high turbidity interferes with and reduces the effectiveness of treatment processes such as the addition of a chemical disinfectant. A multi-barrier approach which uses combinations of technologies should therefore be introduced in our study areas.
- Water quality studies should be given a priority, be integrated into integrated development plans and be conducted on a regular basis to assess risks of contamination in water sources.

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APPENDICES

APPENDIX 1

LETTER OF INFORMATION AND CONSENT

A cross sectional study to determine the water quality that is used by the two rural communities of Masaka : Ayabaraya and Rusheshe. Knowledge, attitudes and practices of the rural communities will also be assessed on water handling, to determine if there is a link to the prevalence of waterborne diseases.

Principal Investigator: Ms Monique Uwimpuhwe

Co- Investigators: Mr. Graham Barratt, Prof Faizal Bux and Dr Poovendhree Reddy

Brief Introduction and purpose of the study:

Waterborne diseases are associated with water polluted by human excreta, poor disposal of sewage and hygiene; and are a major cause of disease and death worldwide and particularly in developing countries. This study will look at the microbiological status of water used by the community in Masaka and to determine if there is no link to the prevalence of waterborne diseases.

The study aims to achieve the following objectives for a 6 months period in 2011

- To measure *e-coli* and total coliforms concentration in water for domestic uses
- To determine the prevalence of waterborne diseases in Masaka in the past 12 months using clinic records
- To assess the knowledge, attitudes and practices of the rural community of Masaka regarding water handling and waterborne diseases.

Outline of procedures:

A trained interviewer will come to your house and you must sign this letter that you are reading now if you want to take part in this study. A questionnaire will be used and you must answer the questions.

Risks or Discomfort to the subject:

There will be no harm to you. It will be greatly appreciated if you take your time to answer the questionnaire.

Benefits:

The study will help to know if water used by the community is safe, if the two communities are aware of the causes of waterborne diseases and what can be done to reduce the prevalence of waterborne diseases. The results will assist in improving the policy on water provision and sanitation in rural areas.

Reasons why the subject may be withdrawn from the study:

If you fill that you cannot continue answering the questions you are allowed to stop. Nothing will happen to you if you do not want to take part in the study.

Costs of the study:

You will not pay to take part in this study.

Confidentiality:

The questionnaire used in the interview will be treated confidentially. Only the researcher will have access to your identification.

Research –related injury:

You will not be paid because you will not be hurt in this study.

People to contact in the event of any problems or queries:

Ms Monique Uwimpuhwe	Tel (mobile): 0788509418
Mr. Graham Barratt	Tel: (+27) 31 373 2655
Prof Faizal Bux	Tel: (+27) 31 373 2778
Dr Poovendhree Reddy	Tel: (+27) 31 373 2808

Statement of agreement to participate in the research study:

I………………………………………………………………………………………………………

(Subject's name and ID number)

Have read this document in its entirety and understand its contents. Where I have had any questions or queries, these have been explained to me by ………………………………………………………to my satisfaction. Furthermore, I fully understand that I may withdraw from this study at any stage without any adverse consequences and my future health care will not be compromised. I, therefore voluntary agree to participate in this study.

Subject's name (print):……………………….Subject's signature…………….Date………….

Researcher's name(print):…………………..Researcher's signature…………Date…………

Witness name (print):………………………Witness signature……………….Date………….

Supervisor's name:…………………………Supervisor's signature…………..Date…………

Fingerprint of participant

IBARWA YO KUMENYESHA NO KWEMEZA

Ubu bushakashatsi bugamije kumenya ubwandure bw'amazi akoreshwa n'abaturage bo mu tugali twa Ayabarabaya na Rusheshe mu murenge wa Masaka. Ubu bushakashatsi bazareba no ku bumenyi ndatse n'ibikorwa by'abaturage ku bijyanye n'uko amazi afatwa mu ngo n' indwara z'impiswi kugirango hagenzurwe isano yabyo n'ubwiganze bw'izo ndwara.

Umushakashatsi: Uwimpuhwe Monique
Abafatanya n'umushakashatsi: Mr. Graham Barratt, Prof Faizal Bux na Dr Poovendhree Reddy

Iriburiro rigufi n'intego rusange y'ubu bushakashatsi

Indwara z'impiswi zituruka ku mazi yandujwe n'umwanda w'abantu ndetse n'inyamaswa, n'isuku nke. Nizo ntandaro y'uburwayi ndetse n'indi ku isi yose by'umwihariko mu bihugu bikiri mu nzira y'amajyambere. Ubu bushakashatsi buziga ku dukoko dutera indwara tuba mu mazi akoreshwa muri Masaka, ku bumenyi bw'abaturage ku mikoreshereze y'amazi n'indwara z'impiswi hamwe n'isano bifitanye n'ubwiganze bwazo muri utu tugali.

Intego zihariye z'ubu bushakashatsi ni izi zikurikira:

- Gupima *E coli* na *kolifolumu* mu mazi akoreshwa mu ngo
- Kumenya umubare w'indwara z'impiswi muri Masaka mu mezi 12 ashize hifashishijwe raporo yo kukigo nderabuzima cya Masaka
- Kureba ubumenyi n'ibikorwa by'abaturage ku bijyanye n'ifatwa ry'amazi mu ngo n'indwara z'impiswi n'isano bifitanye n'umubare wazo

Uko bizakorwa:

Umugenzuzi wabihuguriwe azaza mu rugo rwawe, uzabanza usinye iyi barwa urimo gusoma niba ushaka kugira uruhare muri ubu bushakashatsi.

Ingaruka zaba kuwagize uruhare muri ubu bushakashatsi

Ntangaruka zizaturuka kuri ubu bushakashatsi. Tuzashimishwa cyane ko wafata umwanya wawe ugasubiza ibi bibazo.

Akamaro k'ubu bushakashatsi:

Ubu bushakashatsi buzafasha kumenya niba amazi akoreshwa muri utu tugali twa Ayabaraya na Rusheshe ari meza, niba abaturage baho bazi ibitera indwara z'impiswi no kureba icyakorwa kugirango umubare w'izi ndwara zigabanuke. Ibizavamo bizafasha mu kuvugurura amabwiriza mu bikorwa bijyanye n'itangwa ry'amazi ndetse n'isiku n'isukura mu byaro.

Impamvu zatuma umuntu areka kugira uruhare muri ubu bushakashatsi:

Uramutse wumvise udashobora gukomeza gusubiza ibi bibazo wemerewe kubihagarika. Nta ntangaruka mbi uzagira niba udashaka kugira uruhare muri ubu bushakashatsi.

Igiciro cyo kugira uruhare muri ubu bushakashatsi:

Ntabwo uzishyura kugirango ugire uruhare muri ubu bushakashatsi.

Ibanga ry'ubu bushakashatsi:

Urupapuro rw'ibibazo rwakoreshejwe muri ubu bushakashatsi ruzakoreshwa mu ibanga. Umushakashatsi wenyine uzamenya umwirondoro wawe.

Ibikomere byaturuka kuri ubu bushakashatsi:

Nta nyishyu izabaho muri ubu bushakashatsi kubera ko nta bikomere ubu bushakashatsi buzatera.

Abantu wahamagara igihe waba ugize ibibazo cyangwa ibyo ushaka gusobanuza:

Ms Monique Uwimpuhwe	Tel (mobile): 0788509418
Mr. Graham Barratt	Tel: (+27) 31 373 2655
Prof Faizal Bux	Tel: (+27) 31 373 2778
Dr Poovendhree Reddy	Tel: (+27) 31 373 2808

Icyemezo cyo kugira uruhare muri ubu bushakashatsi

Njyewe……………………………………………………………………… (Izina ry'usubiza)

Nasomye neza uru rwandiko kandi numvise neza ibirukubiyemo. Aho ntasobanukiwe neza cyangwa nagize ikibazo nahasobanuriwe neza na …………………………………………

Nasobanukiwe neza ko nshobora kuhagarika kugira uruhare muri ubu bushakashatsi igihe icyo aricyo cyose nta ngaruka zibayeho, kandi ko nta bikomere cg izindi ngaruka ku buzima bwanjye mu gihe kizaza. None rero niyemeje kugira uruhare muri ubu bushakashatsi.

Izina ry'uwasubije…………………………………Isinya…………… Italiki……………….

Izina ry'umushakashatsi………………………….Isinya…………….Italiki……………….

Izina ry'umugabo…………………………………Isinya……………..Italiki……………….

Izina rya superiviseri…………………………….. Isinya……………..Italiki………………..

Igikumwe cy'uwasubije

APPENDIX 2

MoniqueUwimpuhwe
Durban University of Technology
Dept. Community Health Studies

Environmental Health

Box 1334
Durban 4000
South Africa

Tel: (+27) 739325934

Email: kamonique1@yahoo.fr

To: Mayor of Kicukiro District

Re: Requesting a permission to carry out a study

I am a student registered with Durban University of Technology in South Africa to do a study for my Masters degree in Environmental health. This study will assess the microbiological quality of drinking water used by the communities in Masaka Sector, Kicukiro District, in Rwanda. This study will also include an investigation to determine the knowledge, attitude and practices regarding water handling and waterborne diseases by this community. In order to obtain this data for the study I will require access to clinic records from Masaka Health Centre, to take water samples from the area and to collect information from residents of Rusheshe and Ayabaraya communities in December, 2010. Please note that this study will have several benefits. In the main it will hopefully identify areas of risk in terms of water borne diseases. Further I will also be assessing Rwanda's policy on sanitation and water, which hopefully will identify any needs or shortfalls in this area.

I therefore request permission to carry out this study in the area in question and ask for your written permission in this regard.

Should you require additional information on this matter, please feel free to contact my research supervisors at the Durban University of Technology who will be assisting me.

- Mr. Graham Barratt on jgraham@dut.ac.za or (+27) 31 373 2655
- Prof. Faizal Bux on faizalb@dut.ac.za or (+27) 31 373 2778
- Dr. Poovendhree Reddy on PoovieR@dut.ac.za or (+27) 31 373 2808

Yours Faithfully,

Monique Uwimpuhwe

CC:

- Secretary Executive of Masaka Sector
- Director of Military Hospital of Kanombe
- Director of Caritas Kigali
- Sister In Charge of Masaka Health Centre

APPENDIX 3

Monique Uwimpuhwe
Durban University of Technlogy
Dept. Community Health Studies

Environmental Health

Box 1334

Durban 4000
South Africa

Tel: (+27) 739325934

Email: kamonique1@yahoo.fr

To: Sister In charge of Masak Health Centre

Re: Requesting a permission to carry out a study

I am a student registered with Durban University of Technology in South Africa to do a study for my Masters degree in Environmental health. This study will assess the microbiological quality of drinking water used by the communities in Masaka Sector, Kicukiro District, in Rwanda. This study will also include an investigation to determine the knowledge, attitude and practices regarding water handling and waterborne diseases by this community. In order to obtain this data for the study I will require access to clinic records from Masaka Health Centre, to take water samples from the area and to collect information from residents of Rusheshe and Ayabaraya communities in December, 2010. Please note that this study will have several benefits. In the main it will hopefully identify areas of risk in terms of water borne diseases. Further I will also be assessing Rwanda's policy on sanitation and water, which hopefully will identify any needs or shortfalls in this area.

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- Prof. Faizal Bux on faizalb@dut.ac.za or (+27) 31 373 2778
- Dr. Poovendhree Reddy on PoovieR@dut.ac.za or (+27) 31 373 2808

Yours Faithfully,

Monique Uwimpuhwe

CC:

- Director of Military Hospital of Kanombe
- Mayor of Kicukiro District
- Secretary Executive of Masaka Sector
- Director of Caritas Kigali

APPENDIX 4

QUESTIONNAIRE

KNOWLEDGE, ATTITUDES AND PRACTICES (KAP) ON WATER USAGE AND WATERBORNE DISEASES IN RURAL AREAS OF MASAKA, RWANDA

Please read and complete informed consent form before filling in this questionnaire

<u>INSTRUCTIONS TO THE INTERVIWER</u>

1. Ask the questions and match the answer to the choices.
2. Write an X in the appropriate box.

Place of interview: Rusheshe ☐ 1

Ayabaraya ☐ 2

Date of interview: ______________________________

Interviewer: ______________________ ______________________

First name Surname

A. DEMOGRAPHIC DATA

1. Name of respondent : ____________________________ (Optional)
2. Age: _______________ years
3. Date of birth: _______________

4. How many people living in your household?

4.1.	Children < 5 years	☐
4.2.	Children 6 – 10 years	☐
4.3.	Children 11 – 18 years	☐
4.4.	Adults (> 18 years)	☐

5. Level of education

   - 5.1. No schooling 1
   - 5.2. Some primary schooling 2
   - 5.3. Standard 6-9 3
   - 5.4. High school matriculate 4
   - 5.5. Some tertiary Education 5

B. WATER RELATED INFORMATION

6. Where do you get water from?
   - 6.1. Public tap 1
   - 6.2. Well/Spring/ Borehole 2
   - 6.3. Nyabarongo River 3
   - 6.4. Other (Specify)……………….. 4
7. What type of container do you use to fetch or store water?
   - 7.1. Plastic 1
   - 7.2. Metal 2
   - 7.3. Other (Please specify)…………………… 3
8. How far is the water source from your house? (in meters)
   - 8.1. <50m 1
   - 8.2. 50 – 100m 2
   - 8.3. 100 – 500m 3
   - 8.4. > 500m 4

9. Is the water storage container kept……..?
   - 9.1. Open 1
   - 9.2. Closed 2
10. Is the water kept……..?
    - 10.1. Outdoors 1
    - 10.2. Indoors 2
11. How is water obtained from the storage container for daily use?

11.1. Mug/ container ☐ 1

11.2. Tap ☐ 2

11.3. Other (Please specify)…………………… ☐ 3

12. How often do is your storage container cleaned?

12.1. Daily ☐ 1

12.2. Weekly ☐ 2

12.3. Monthly ☐ 3

12.4. Rarely or not all ☐ 4

13. What do you use to clean the storage container?

13.1. Water only ☐ 1

13.2. Soap and water ☐ 2

13.3. Sand and water ☐ 3

13.4. Other (Specify)…………………… ☐ 4

14. Do you use a separate container for storing drinking water?

Yes ☐ No ☐ 0

15. How do you treat your drinking water at home?

15.1. Boiling ☐ 1

15.2. Add chemicals ("Sûr'Eau" a chlorine- based water disinfection product) ☐ 2

15.3. I don't treat drinking water ☐ 3

15.4. Other (Specify)…………………… ☐ 4

C. SANITATION RELATED INFORMATION

16. Do you have a toilet at home?

Yes ☐ 1 No ☐ 0

17. What is the importance of having a toilet at home?

17.1. To keep the village clean Yes ☐ 1 No ☐ 0

17.2. To keep the village free from odour Yes ☐ 1 No ☐ 0

17.3. To prevent diseases Yes ☐ 1 No ☐ 0

17.4. Privacy Yes ☐ 1 No ☐ 0

17.5. Other (specify)……………………..

18. List the occasions when you wash your hands

18.1. Before eating food	Yes ☐ 1	No ☐ 0
18.2. Before preparing food	Yes ☐ 1	No ☐ 0
18.3. After using a toilet	Yes ☐ 1	No ☐ 0
18.4. After waking up in the morning	Yes ☐ 1	No ☐ 0
18.5. After cleaning the baby's buttocks	Yes ☐ 1	No ☐ 0

19. What do you use to wash your hands?

19.1. Soap and water	☐ 1
19.2. Ash and water	☐ 2
19.3. Plain water	☐ 3
19.4. Sand and water	☐ 4
19.5. Other (Specify)……………………	☐ 5

20. If yes, why do you wash your hands?

20.1. To be clean	Yes ☐ 1	No ☐ 0
20.2. To prevent diseases	Yes ☐ 1	No ☐ 0
20.3. To be healthy	Yes ☐ 1	No ☐ 0

20.4. Other (Specify)……………………

D. KNOWLEDGE AND PRACTICES TOWARD WATERBORNE DISEASES

21. Do you know any diseases caused by dirty water?

Yes ☐ 1 No ☐ 0

Please specify: ____

____

22. Have any of your family members experienced diarrhoeal/ stomach cramps diseases in the last six months?

Yes ☐ 1 No ☐ 0

Elaborate: ____

23. What do you think caused diarrhoea?

23.1. Contaminated water ☐ 1

23.2. Eating stale food ☐ 2

23.3. Eat with dirty hands ☐ 3

23.4. Dirty surroundings ☐ 4

23.5. Religious belief ☐ 5

23.6. Other (Please specify)……………………. ☐ 6

24. Have you ever experienced any symptoms of the following in the last 6 months?

24.1.	Watery stool	Yes ☐ 1	No ☐ 0
24.2.	Passing blood	Yes ☐ 1	No ☐ 0
24.3.	Vomiting	Yes ☐ 1	No ☐ 0
24.4.	More than 4 looses stools in 24 hours	Yes ☐ 1	No ☐ 0

25. Did you report those symptoms to the clinic?

Yes ☐ 1 No ☐ 0

26. Were you given medication for these symptoms? Yes ☐ 1 No ☐ 0

27. What do you do to prevent diarrhoea?

27.1 Treat drinking water	Yes ☐ 1	No ☐ 0
27.2 Keep water in clean and closed container	Yes ☐ 1	No ☐ 0
27.3 Wash hands	Yes ☐ 1	No ☐ 0
27.4 Use and clean toilets	Yes ☐ 1	No ☐ 0

27.5 Other (specify)………………………………….

28. How do you think diarrhoea may be prevented?

29. How do you treat someone with diarrhoea at home?

____

____

____

E. General

Do you have any other comment?

____

____

____

Thank you very much for your participation!

IBIBAZO

UBUSHAKASHATSI KURI MIKOROBE ZIRI MU MAZI N'ISANO AFITANYE N'UMUBARE W'INDWARA ZITURUKA KU MAZI YANDUYE

Mbere yo gusubiza ibi bibazo ubanze usome neza anasinye ibarwa yo kumenyesha no kwemeza

AMABWIRIZA Y'UMUGENZUZI

- Baza ibibazo ubihuze n'ibisubizo byatanzwe
- Andika X mu kazu kabigenewe

Aho ibibazo byatangiwe: Rusheshe ☐ 1

Ayabaraya ☐ 2

Italiki ______________________

Izina ry'umugenzuzi ______________ ______________

A. UMWIRONDORO

1. Izina ry'usubiza ______________________ (kubushake)
2. Imyaka ______________________
3. Italiki yavukiyeho ______________________

4. Muri abantu bangahe mu rugo?

4.1 Abana bari munsi y'imyaka 5		1
4.2 Abari hagati y'imyaka 6 na 10		2
4.3 Abari hagati y'imyaka 11 na 18		3
4.4 Abakuru barengeje imyaka 18		4

5. Umubare w'amashuri afite
   5.1 Ntago yageze mu ishuri ☐ 1
   5.2 Ntiyarangije amashuri abanza ☐ 2
   5.3 Yarangije amashuri abanza ☐ 3
   5.4 Yarangije amashuri yisumbuye ☐ 4
   5.5 Yageze mu mashuri ahanitse ☐ 5

B. IBIBAZO BIJYANYE N'AMAZI

6. Mukura he amazi mukoresha mu rugo?
   6.1 Kuri robine ☐ 1
   6.2 Ku isoko ☐ 2
   6.3 Kuri Nyabarongo ☐ 3
   6.4 Ahandi (havuge) …………… ☐ 4
7. Mukoresha iki muvoma cyangwa mubika amazi?
   7.1 Palastike ☐ 1
   7.2 Icyuma ☐ 2
   7.3 Ikindi (kivuge)…................... ☐ 3

8. Aho muvoma amazi ni kure hangana iki?
   8.1 <50m ☐ 1
   8.2 50 – 100m ☐ 2
   8.3 100 – 500m ☐ 3
   8.4 > 500m ☐ 4
9. Icyo mushyiramo amazi mukibika……………..?
   9.1 gipfundikiye ☐ 1
   9.2 Gipfunduye ☐ 2

10. Amazi muyabika………..?
    10.1 Hanze ☐ 1
    10.2 Munzu ☐ 2
11. Mukoresha iki mukura amazi mucyo muyabikamo?

11.1 Igikombe/ Ikindi kintu cyo kudahisha ☐ 1

11.2 Gifite robine ☐ 2

11.3 Ikindi (kivuge) ☐ 3

12. Ni kangahe mwoza icyo mubikamo amazi?

12.1 Buri munsi ☐ 1

12.2 Rimwe mu cyumweru ☐ 2

12.3 Rimwe mu kwezi ☐ 3

12.4 Gake/ ntanarimwe ☐ 4

13. Niba mucyoza, mukoresha iki?

13.1 Amazi gusa ☐ 1

13.2 Amazi n'isabune ☐ 2

13.3 Umucanga n'amazi ☐ 3

13.4 Ikindi (kivuge)………..…………….. ☐ 4

14. Icyo mubikamo amazi yo kunywa kitandukanye n'icyo mubikamo amazi mukoresha ibindi?

Yego 0 ☐ Oya 1 ☐

15. Ni iki mukorera amazi mbere yo kuyanywa?

15.1 Kuyateka ☐ 1

15.2 Gushyiramo Sur'Eau ☐ 2

15.3 Ntacyo ☐ 3

15.4 Ikindi (kivuge)………………………… ☐ 4

C. IBIBAZO BIJYANYE N'ISUKU

16. Mufite umusarani hano mu rugo?

Yego ☐ 0 Oya ☐ 1

17. Ni akahe kamaro ko kugira umusarani mu rugo?

17.1 Kurinda abaturanyi umwanda Yego 1 ☐ Oya ☐ 0

17.2 Kurinda abaturanyi umunuko Yego 1 ☐ Oya ☐ 0

17.3 Kwirinda indwara Yego 1 ☐ Oya ☐ 0

17.4 Kugira ubwiherero Yego 1 ☐ Oya ☐ 0

17.5 Ikindi (kivuge)………………………

18. Ni ryari ukaraba intoki?

18.1	Mbere yo kurya	Yego ☐ 1	Oya ☐ 0
18.2	Mbere yo gutunganya	Yego ☐ 1	Oya ☐ 0
18.3	Nyuma yo kuva mu musarani	Yego ☐ 1	Oya ☐ 0
18.4	Mbyutse	Yego ☐ 1	Oya ☐ 0
18.5	Maze guhanagura umwana amaze kwituma	Yego ☐ 1	Oya ☐ 0

19. Ukoresha iki ukaraba intoki?

19.1	Amazi n'isabune	☐	1
19.2	Ivu n'amazi	☐	2
19.3	Amazi gusa	☐	3
19.4	Umucanga n'amazi	☐	4
19.5	Ikindi (kivuge)……………………………	☐	5

20. Ni akahe kamaro ko gukaraba intoki?

20.1	kugira ngo use neza	Yego ☐ 1	Oya ☐ 0
20.2	Kwirinda ibyorezo	Yego ☐ 1	Oya ☐ 0
20.3	Kwirinda indwara	Yego ☐ 1	Oya ☐ 0
20.4	Ikindi (kivuge)……………………………		

D. IBIBAZO KU BUMENYI IMYITWARIRE N'IBIKORWA KU BIJYANYE N'INDWARA ZITURUKA KU MAZI YANDUYE

21. Hari indwara uzi ziterwa n'amazi yanduye?

Yego ☐ 0 Oya ☐ 1

Ni izihe uzi: ______________________________

22. Hari umuntu hano waba uherutse kurwara impiswi mu mezi atandatu ashize?

Yego ☐ 0 Oya ☐ 1

Sobanura: ______________________________

23. Niba ari yego, iki wumva cyaba cyarateye izo mpiswi?

23.1 Amazi yanduye? ☐ 1

23.2 Kurya ibiryo bigaze ☐ 2

23.3 Kurisha intoki zanduye ☐ 3

23.4 Umwanda udukikije ☐ 4

23.5 Imyizerere ☐ 5

23.6 Ikindi (kivuge)…………………………. ☐ 6

24. Waba waragize ibimenyetso bikurikira mu mezi atandatu ashize?

24.1 Umusarani w'amazi Yego ☐ 1 Oya ☐ 0

24.2 Umusarani w'amaraso Yego ☐ 1 Oya ☐ 0

24.3 Kuruka Yego ☐ 1 Oya ☐ 0

24.4 Guhitwa Yego ☐ 1 Oya ☐ 0

24.5 Oya Yego ☐ 1 Oya ☐ 0

25. Niba warabigize wagiye kwa muganga

Yego ☐ 0 Oya ☐ 1

26. Niba ari yego ni iyihe miti baguhaye?

____

____

27. Ni gute wirinda indwara z'impiswi?

27.1 Gusukura amazi Yego ☐ 1 Oya ☐ 0

27.2 kubika amazi mu bikoresho bisukuye kandi bipfundikirwa

Yego ☐ 1 Oya ☐ 0

27.3 Gukaraba intoki Yego ☐ 1 Oya ☐ 0

27.4 Kwituma mu musarani Yego ☐ 1 Oya ☐ 0

27.5 Ikindi (kivuge)……………………………………

28. Ni iki wumva cyakorwa kugira ngo abantu birinde impiswi?

____

____

____

29. Ni gute wavura umuntu wagize impiswi mu rugo?

E. IBINDI

30. Hari icyo wakongeraho kubijyanye n'ibibazo byabajijijwe haruguru?

Murakoze

APPENDIX 5

CLINIC RECORDS CHECKLIST

Clinic Name: ……………………………………….

Kicukiro District

Date	Village	Age/ date of birth	Gender	Reason for visit	Symptoms	Treatment