Evaluating the post-implementation effectiveness of selected household water treatment technologies in rural Kenya

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ABSTRACT

Water, sanitation and hygiene-related diseases are responsible for 7% of all deaths and 8% of all disability adjusted live years (DALYs), as well as the loss of 320 million days of productivity in developing countries. Though laboratory and field trials have shown that household water treatment (HWT) technologies can quickly improve the microbiological quality of drinking water, questions remain about the effectiveness of these technologies under real-world conditions. Furthermore, the value that rural communities attach to HWT is unknown, and it is not clear why, in spite of the fact that rural African households need household water treatment (HWT) most, they are the least likely to use them.

The primary objective of this multi-level study was to assess the post-implementation effectiveness of selected HWT technologies in the Nyanza and Western Provinces of Kenya. The study was carried out in the rainy season between March and May, 2011 using a mixed method approach. Evidence was collected in order to build a case of evidence of HWT effectiveness or ineffectiveness in a post-implementation context. A quasi-experimental design was used first to conduct a Knowledge, Attitudes and Practices (KAP) survey in 474 households in ten intervention and five control villages (Chapter 3). The survey assessed the context in which household water treatment was being used in the study villages to provide real-world information for assessing the effectiveness of the technologies. An interviewer-administered questionnaire elicited information about the water, sanitation and hygiene-related KAP of the study communities. A household water treatment (HWT) survey (Chapter 4) was carried out in the same study households and villages as the KAP study, using a semi-structured questionnaire to gather HWT adoption, compliance and sustained use-related information to provide insight into the perceived value the study households attach to HWT technologies, and their likelihood of adoption of and compliance with these technologies. The drinking water quality of 171 (one quarter of those surveyed during KAP) randomly selected households was determined and tracked from source to the point of use (Chapter 5). This provided insights into HWT effectiveness by highlighting the need for HWT (as indicated by source water quality) and the effect of the study households' KAP on drinking water quality (as indicated by the stored water quality). Physico-chemical and microbiological water quality of the nineteen improved and unimproved sources used by the study households was determined, according to the World Health Organisation guidelines. The microbiological quality of 291 water samples in six intervention and five control villages was determined from source to the point-of-use (POU) using the WHO and Sphere Drinking Water Quality Guidelines. An observational study design was then used to assess the post-implementation effectiveness of the technologies used in 37 households in five intervention villages (Chapter 6). Three assessments were carried out to determine the changes in the microbiological quality of 107 drinking water samples before treatment (from collection container) and after treatment (from storage container) by the households. The criteria used to assess the performance of the technologies were microbial efficacy, robustness and performance in relation to sector standards. A Quantitative Microbial Risk Assessment (QMRA) was then carried out in the HWT effectiveness study households to assess the technologies' ability to reduce the users' exposure to and probability of infection with water-borne pathogens (Chapter 7).

The KAP survey showed that the intervention and control communities did not differ significantly in 18 out of 20 socio-economic variables that could potentially be influenced by the structured manner of introducing HWT into the intervention villages. The majority of the intervention group (IG) and the control group (CG) were poor or very poor on the basis of household assets they owned. The predominant level of education for almost two-thirds of the IG and CG respondents was primary school (completed and non-completed). Though very few were unemployed in IG (8.07%) and CG (14.29%), the two groups of respondents were predominantly engaged in subsistence farming — a low income occupation. With regard to practices, both groups had inadequate access to water and sanitation with only one in two of the households in both IG and CG using improved water sources as their main drinking water source in the non-rainy season. One in ten households in both study groups possessed an improved sanitation facility, though the CG was significantly more likely to practice open defecation than the IG. The self-reported use of soap in both study groups was mainly for bathing and not for handwashing after faecal contact with adult or child faeces. Despite the study groups' knowledge about diarrhoea, both groups showed a disconnection between their knowledge about routes of contamination and barriers to contamination. The most frequent reason for not treating water was the perceived safety of rain water in both the IG and CG.

The HWT adoption survey revealed poor storage and water-handling practices in both IG and CG, and that very few respondents knew how to use the HWT technologies correctly: The IG and CG were similar in perceived value attached to household water treatment. All HWT technologies had a lower likelihood of adoption compared to the likelihood of compliance indicators in both IG and CG. The users' perceptions about efficacy, time taken and ease of use of the HWT technologies lowered the perceived value attached to the technologies.

The assessment of the drinking water quality used by the study communities indicated that the improved sources had a lower geometric mean *E. coli* and total coliform count than the unimproved sources. Both categories of sources were of poor microbiological quality and both exceeded the Sphere Project (2004) and the WHO (2008) guidelines for total coliforms and *E. Coli* respectively The study communities' predominant drinking water sources, surface water and rainwater were faecally contaminated (geometric mean *E. coli* load of 388.1±30.45 and 38.9±22.35 cfu/100 ml respectively) and needed effective HWT. The improved sources were significantly more likely than the unimproved sources to have a higher proportion of samples that complied with the WHO drinking water guidelines at source, highlighting the importance of providing improved water sources. The lowest levels of faecal contamination were observed between the collection and storage points which coincided with the stage at which HWT is normally applied, suggesting an HWT effect on the water quality. All water sources had nitrate and turbidity levels that exceeded the WHO stipulated guidelines, while some of the improved and unimproved sources had higher than permissible levels of lead, manganese and aluminium. The water source category and the mouth type of the storage container were predictive of the stored water quality. The active treater households had a higher percentage of samples that complied with WHO water quality guidelines for *E. coli* than inactive treater households in both improved and unimproved source categories. In inactive treater households, 65% of storage container water samples from the improved sources complied with the WHO guidelines in comparison to 72% of the stored water samples in the active treater households. However the differences were not statistically significant. The HWT technologies did not attain sector standards of effective performance: in descending order, the mean $\log_{10}$ reduction in *E. coli* concentrations after treatment of water from unimproved sources was PUR ($\log_{10}$ 2.0), ceramic filters ($\log_{10}$ 1.57), Aquatab ($\log_{10}$ 1.06) and Waterguard ($\log_{10}$ 0.44). The mean $\log_{10}$ reduction in *E. coli* after treatment of water from improved sources was Aquatab ($\log_{10}$ 2.3), Waterguard ($\log_{10}$ 1.43), PUR ($\log_{10}$ 0.94) and ceramic filters ($\log_{10}$ 0.16).

The HWT technologies reduced the user's daily exposure to water-borne pathogens from both unimproved and improved drinking water sources. The mean difference in exposure after treatment of water from unimproved sources was ceramic filter ($\log_{10}$ 2.1), Aquatab ($\log_{10}$ 1.9), PUR ($\log_{10}$ 1.5) and Waterguard ($\log_{10}$ 0.9), in descending order. The mean probability of infection with water-borne pathogens (using *E.coli* as indicator) after consumption of treated water from both improved and unimproved sources was reduced in users of all the HWT technologies. The difference in reduction between technologies was not statistically significant.

The study concluded that despite the apparent need for HWT, the study households' inadequate knowledge, poor attitudes and unhygienic practices make it unlikely that they will use the technologies effectively to reduce microbial concentrations to the standards stipulated by accepted drinking water quality guidelines. The structured method of HWT promotion in the intervention villages had not resulted in more hygienic water and sanitation KAP in the IG compared to the CG, or significant differences in likelihood of adoption and compliance with the assessed HWT technologies. Despite attaching a high perceived value to HWT, insufficient knowledge about how to use the HWT technologies and user concerns about factors such as ease of use, accessibility and time to use will impact negatively on adoption and compliance with HWT, notwithstanding their efficacy during field trials. Even though external support had been withdrawn, the assessed HWT technologies were able improve the quality of household drinking water and reduce the exposure and risk of water-borne infections. However, the improvement in water quality and reduction in risk did not attain sector guidelines, highlighting the need to address the attitudes, practices and design criteria identified in this study which limit the adoption, compliance and effective use of these technologies. These findings have implications for HWT interventions, emphasising the need for practice-based behavioural support alongside technical support.

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LIST OF ABBREVIATIONS

CADDIS	Causal Analysis/Diagnosis Decision Information System
CDC	Center for Disease Control
CG	Control Group
CFU	Colony-Forming Units
DALYs	Disability Adjusted Live Years
DFID	Department for International Development
DHS	Demographic Health Survey
DWA	Department of Water Affairs
EC	European Commission
EU	European Union
FAC	Free Available Chlorine
HIV/AIDS	Human Immunodeficiency Virus/Acquired Immune Deficiency Syndrome
HWT	Household Water Treatment
IG	Intervention Group
JMP	Joint Monitoring Programme
KAP	Knowledge, Attitude and Practice
KDHS	Kenyan Demographic Health Survey
KES	Kenyan Shillings
KNBS	Kenyan National Bureau of Statistics
KWAHO	Kenya Water for Health Organization
MDG7	Millennium Development Goal 7
NaDCC	Sodium dichloroisocyanurate
NGO	Non Governmental Organisation

NTU	Nephelometric Turbidity Unit
OECD	Organisation of Economic Cooperation and Development
PAO	Pan-American Organisation
PET	Polyethylene Terephthalate
POU	Point-of-Use
QMRA	Quantitative Microbial Risk Assessment
SODIS	Solar disinfection
RSA	Republic of South Africa
TNTC	Too numerous to count
WASH	Water, Sanitation and Hygiene
WBCSD	World Business Sustainable Council
WISER	Women’s Institute of Secondary Education and Research
WHO	World Health Organisation
U5	Child below five years
UNICEF	United Nations Children Fund
UN	United Nations
UNESCO	United Nations Educational and Scientific and Cultural Organisation
VIP	Ventilated Improved Pit

GLOSSARY

Causal Analysis Diagnosis Decision Information System (CADDIS) scoring system: Qualitative weighting system which assigns + or – signs to a piece of evidence. +++ or --- represents convincingly supports or weakens to + or – somewhat supports or weakens, and 0 represents no effect (Suter and Cormier, 2011).

Setting: Water and sanitation related context in relation to drinking water (Wright *et al.*, 2004).

Typical-use: Use of HWT without external support (Mclaughlin *et al*., 2009)

Real-world: Use of HWT after implementation period (Mclaughlin *et al*., 2009)

DEDICATION

I dedicate this work to my father who wanted me to do a PhD and to my mother who prayed for me to get it and to Big Dad who answered the prayers.

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DECLARATION

In accordance with the regulations for the award of the degree of Doctor of Philosophy, I declare that the work presented in this thesis is my own original research. This thesis has not been submitted to any other university.

1. GENERAL INTRODUCTION AND LITERATURE REVIEW

This chapter presents a background to the study, the study's aim and objectives, and reviews literature related to household water treatment in developing countries.

1.1 General Background

The huge financial and logistic requirements of providing pipe-borne water at the household level to everyone has resulted in the use of decentralised community supply interventions as a major strategy to meet the safe water-related Millennium Development Goal 7 (MDG7) with considerable financial investments still being made. The World Bank, for example, invested US$5.5 billion in rural water and sanitation between 1978 and 2003 (Clark and Gundry, 2004). Though piped water supplies can be contaminated, decentralised water supplies are more vulnerable to contamination (Younes and Bartram, 2001 and Clasen *et al.*, 2007a) because individual households need to transport and store the collected water (Cairncross and Feachem, 1993; DFID, 1998; Gleick, 2002). Furthermore, the water supply technologies depend on communities and households for operation and maintenance (Meierhofer and Landolt, 2009).

Recontamination of water supplies has been investigated by Jagals (2003), Wright *et al.* (2004), Gundry *et al.* (2006), and these studies show that water that is microbiologically safe at source may become contaminated during the processes of collection and storage, when water is supplied through communal standpipes, rendering such water unsafe for human consumption at the point-of-use. This pattern of recontamination was also observed in Kenya where a baseline survey of the 22 UNICEF supported districts in Kenya found evidence of microbiological contamination in 62% of the water sources, and reported that drinking water which had been safe at the source was subject to frequent and extensive faecal contamination during collection, storage and use in the home (UNICEF, 2010a).

Recontamination of water supplies has been attributed to the knowledge, attitudes and practices (KAP) of communities in relation to water handling, sanitation and hygiene. KAP studies have shown that the sanitation and hygiene-related sources of recontamination include poor human excretal disposal (Banda *et al.*, 2007); not washing hands with soap after defecation or cleaning children's defecation (Hoque *et al.*, 1995). Other factors include a poor knowledge of the association between diarrhoea and water handling and sanitation and hygiene practices (Banda *et al.*, 2007), poor source protection and poor knowledge of household water treatment options (Onabolu *et al.*, 2011).

The poor KAP of households results in recontamination, which in turn leads to poor water quality, at the point-of-consumption, and has a severe impact on human health (Wright *et al.*, 2004), particularly in the developing world where mortality rates from inadequate access to water and sanitation are higher than those experienced in developed countries (Sobsey *et al.*, 2008; Rehfuess *et al.*, 2009). Water sanitation and hygiene-related diseases are responsible for 7% of all deaths and 8% of all disability adjusted live years (DALYs) lost in developing countries, which is second only to malnutrition, which is responsible for 15% of all deaths and 18% of all DALYs lost (Mara, 2003).

In 2002, more than 120 000 cases of cholera morbidity were reported worldwide, and in the first seven months of 2003, 18 224 cholera cases occurred in South Africa with a 0.22% case fatality rate (DOH, 2003). There is a global recognition that maintaining the microbiological water quality to prevent recontamination to the point-of-use is critically important (Figure 1.1).

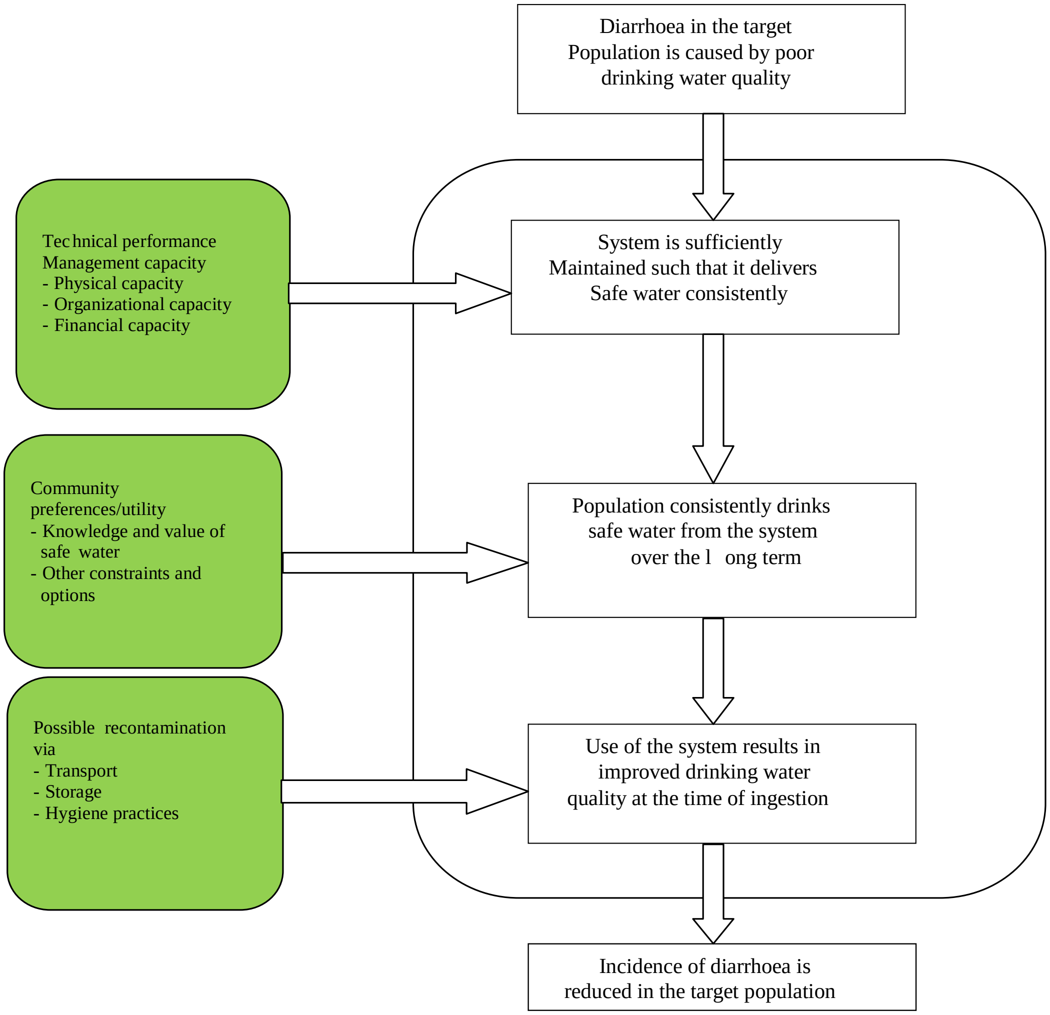


Figure 1.1 Overview of system for maintaining microbiological quality from source to point-of-use. Source: deWilde *et al.* (2008).

This can be achieved either by providing pipe-borne water at household level (Stevenson, 2008) or promoting low-cost household water treatment (HWT) interventions (Clasen and Cairncross, 2004). Stevenson (2008) queried the feasibility of the first option as most low and middle-income countries lack the required capital to treat and reticulate water to household level for all its citizens. Younes and Bartram (2001) noted that it was estimated that US$13 billion per year would be needed to extend coverage to those without access to improved water supply between 1990 and 2000. With regard to the second option, WHO (2007) noted that various studies have shown the impact of low-cost community and household level water quality interventions on improving the microbiological quality of stored water. Wright *et al.* (2004) recommend household water treatment and storage as a preventive measure, cautioning that policies that attempt to improve water quality by focusing on water supply may be compromised by post-collection contamination. The use of HWT is especially pertinent in sub-Saharan Africa where 37% of the 884 million people who use unimproved sources live (WHO/UNICEF, 2010). Household water treatment is also relevant in Kenya were two out of every five persons have inadequate access to safe water (WHO/UNICEF, 2010).

Low-cost HWT technologies are therefore being promoted to maintain the microbiological quality of water to the point-of-use (Clasen and Cairncross, 2004). For instance, Schmidt and Cairncross (2008) and Sobsey *et al.* (2008) noted that people are being taught how to treat their water at home with HWT technologies as a strategy to reduce diarrhoeal diseases. Examples of these technologies include filtration, chlorination, combined flocculant and disinfectant, and solar disinfection (Sobsey *et al.,* 2008).

However, there is a school of thought that doubts the effectiveness of HWT technologies (Kirchhoff *et. al.*, 1985; Eisenberg *et al.,* 2007), while another school of thought submits that even if they are effective under laboratory and actual field conditions, they may not continue to be so over long periods of use (Sobsey *et al.,* 2008). For instance, Schmidt and Cairncross (2008), noted that current widespread promotion of HWT is premature, and that more studies are necessary to determine the acceptability and impact of HWT on diarrhoea. Zwane and Kremer (2007) though, maintain that the case for the effectiveness of point-of-use water treatment has been established, but admit that many of the instances in which a high uptake of HWT has occurred were as a result of daily follow-up by field workers which, they cautioned, is prohibitively expensive to maintain.

Sobsey *et al.* (2008: 4261) summarised the differences in opinion as “a lack of rigorous scientific evidence of sustained use, positive health impact and water quality improvement over extended periods of use by the different point-of-use (POU) technologies”. They warned that this makes it difficult for policy makers, implementers, and users to select appropriate options for particular situations, hindering large-scale promotion and uptake of the technologies and their inclusion in national development plans.

The effectiveness of these technologies, especially after a trial and promotion period, needs further investigation. Notwithstanding these uncertainties, donor agencies and governments are investing money and promoting HWT interventions as a method of accelerating access to safe drinking water by those currently underserviced. Hence it is necessary to carry out a study which addresses the gap in information about the effectiveness of household water treatment technologies after the intervention period when households use HWT without external support.

Any post-implementation study would need to examine the effectiveness of HWT practice within a real-world context, and would need to use a “multi-lens” approach. For example, in order to assess the effectiveness of HWT technologies when used in real-world situations without external support, it is important to understand the factors responsible for water quality contamination even when protected sources are used.

A meta-analysis of 57 studies noted a significantly greater decline in microbial quality from source to point-of-use which was related to the setting of the study (Wright *et al.*, 2004). Therefore, in view of the role that the setting and the knowledge, attitudes and practices of the user households play in determining drinking water quality, and the need for HWT, it is important that the KAP of the particular study communities in which HWT technologies are being assessed is investigated. This is necessary because, though KAP studies have been carried out in relation to drinking water quality, very few have been carried out as part of the assessment of HWT effectiveness and within a real-world context.

Reasons for HWT adoption also need to be examined as part of a study assessing the post-implementation effectiveness of HWT (Waddington *et al.*, 2009) because, after a systematic review of 56 water and sanitation studies, Waddington *et al*. (2009), noted that existing water and sanitation impact studies only assess levels of effectiveness without determining the reasons for the observed levels. Consequently even when levels of effectiveness of the different types of HWT are known, the reasons for the levels observed, particularly from the users’ perspectives, remain unclear. They point out that this makes it difficult to review technologies and improve their efficacy at the household level. deWilde *et al.* (2008) noted that, in order to evaluate the overall health impacts or effectiveness of safe water interventions and programs, it is necessary to improve the sectoral understanding of why a water treatment program fails or succeeds.

deWilde *et al.* (2008) advised that this should be done by systematically analysing the technical, behavioural and other factors which affect the performance of systems. Since effectiveness of an intervention is a measure of the levels of its adoption and its sustainability (Waddington *et al.*, 2009), it is necessary to investigate the value attached to HWT intervention by the study communities as this will determine the likelihood of adoption and compliance with HWT.

In addition to the reasons for adoption of HWT, it is important to know if decentralized stand-alone water sources in rural communities provide safe drinking water from source to point-of-use, or whether they should be supplemented with household water treatment and safe storage (HWT). Clasen (2010) observed that improved sources, such as protected wells and communal standpoints may provide water of poor quality at source due to poor sanitary surroundings. Concurring, Wright *et al*. (2004) noted that water supply interventions may be compromised by post-collection contamination and recommended household water treatment and storage as a preventive measure. The recommendation of HWT as a solution to post-collection contamination contradicts Esrey *et al.* (1985) and Esrey *et al.'s* (1991) findings which suggested a limited effectiveness of water quality interventions and recommended water supply interventions. In order to ascertain whether decentralised technologies provide safe water quality to the point-of-use, it is necessary for this multi-lens study to investigate the changes in microbial quality, if any, from the source to the collection and storage containers of the study households. Previous studies that have tracked water quality have examined only the source and storage containers, neglecting the collection containers, which is the stage at which households that practice HWT treat their water.

A multi-lens HWT study should be carried out post-implementation because of disagreement in the sector about the long-term effectiveness of the HWT interventions. For example, Luby *et al.* (2008) agree that various small-scale studies have shown that persons who live in households that treat their water with microbiologically effective point-of-use water treatment methods have fewer episodes of diarrhoea than those who live in households that do not treat their water. Mintz *et al.* (2001); Clasen and Bastable (2003); Wright *et al.* (2004) concur with this view noting that because decentralized community-level systems cannot guarantee water that is consistently safe at the point-of-use, it is necessary to extend protection to the point-of-use and to expand access to HWT, water storage and water quality monitoring at the point of consumption. Luby *et al*. (2008) however, caution that most information on effectiveness of the methods is obtained from experiments or efficacy studies which do not reflect real-world situations. It is therefore necessary to assess the effectiveness of household water treatment technologies as used by the households when all external support, hygiene promotion, and external monitoring have ended.

Related to assessing the post-implementation effectiveness of HWT technologies is the need to assess their ability to reduce the risks of water-borne diseases to users of HWT. Because water supplies which meet the WHO guidelines for improved water may still be heavily contaminated with faecal matter, the implication is that the actual figures of those at risk of dying from diarrhoeal diseases exceed the 1.1 billion people who have no access to improved water sources (Luby *et al.*, 2008). Furthermore, although various authors have indicated that HWT technologies have been shown to improve water quality significantly and reduce the risk of water-borne infections (Fewtrell and Colford, 2004; Clasen *et al*., 2007b), the validity of the results has been queried. The assessment of the risk reduction by the HWT technologies has usually been carried out through intervention studies that use diarrhoea as an outcome, giving rise to various validity criticisms such as recall bias, non-blinding and the inadequate use of controls (Blum and Feachem, 1983; Schmidt and Cairncross, 2008). For instance, Schmidt and Cairncross (2008) caution that sectoral reports of a 30–40% diarrhoea reduction with the use of HWT technologies may be strongly biased. It is necessary to carry out an assessment of the effect of HWT technologies using a Quantitative Microbial Risk Assessment (QMRA) method, to reduce the bias and address other validity concerns of previous HWT impact studies. Though QMRA's have been carried out in relation to drinking water quality, none have been carried out in relation to household water treatment technologies.

1.2 Problem statement

There is insufficient knowledge about the sustained effectiveness of household water treatment technologies and the reasons for user adoption and continued compliance after the water quality intervention (laboratory or field trial period). This limits the sector's ability to make informed decisions about the types of household water treatment technology to invest in, and to be alerted to any other kind of support needed, decisions that will achieve the intended health benefits of household water treatment.

1.3 Rationale of the study

This study assessed the post-implementation effectiveness of household water treatment technologies, using a multi-lens approach to identify gaps in knowledge about HWT technologies, their sustained effectiveness and health benefits. The study context was rural Kenya, representative of other communities in rural Africa, where the poor, who form approximately 70% of the Kenyan population, are mostly affected by the disease burden of inadequate access to safe water, because most of them obtain water for domestic purposes directly from rivers, lakes, dams, streams and impoundments (UNESCO, 2006).

The drinking water supply and sanitation sector (referred to as ‘sector’) uses the provision of safe water through decentralized community supply interventions as the major strategy for reducing the incidence of water-borne diseases like cholera and other diarrhoeal diseases. There are, however, multiple avenues of contamination between source and storage which, again, expose consumers of such recontaminated water sources to the water-borne diseases. It is therefore vital to maintain the microbiological quality of the provided drinking water sources from source to point-of-use to protect consumers from the health risks of microbiologically unsafe drinking water. Low-cost household water treatment is the more financially feasible of the two main options for maintaining microbial quality; the other is the provision of piped-water at household level, which is not financially feasible in the short-term.

Though studies have reported positively on the efficacy of these low-cost HWT technologies, the sector acknowledges that there is a gap in current information about the effectiveness of HWT technologies in the long term, the perceived value and likelihood of adoption of the HWT technologies, and the reduction in water and sanitation-related health risks to the consumers of the water treated at the household level. These gaps in sector knowledge prevent governments from integrating HWT technologies into their development plans and limit access to HWT technologies and their health benefits. This study provides policy makers and planners with required scientific evidence to facilitate investment-related decision making and to scale-up and include HWT in national development strategies.

1.4 Research questions

1. What are the knowledge, attitudes and practices (KAP) of the study communities in relation to water, sanitation and hygiene, and how are these related to effective household water treatment?
2. What is the likelihood of adopting and complying with HWT technologies based on the perceived value households attach to the technologies?
3. What are the changes in microbial quality of drinking water if any, from source to point-of-use, at which stage is water recontaminated, and how is the observed stored water quality related to knowledge, attitudes and practices?
4. How effective are the selected household water treatment technologies after the promotion/trial period within the intervention and control communities?
5. What is the effect of the selected HWT technologies on the risk of water-borne infections, using *E. coli* as an indicator?

1.5 Study aim and objectives

This multi-lens study aims to assess the effectiveness of selected household water treatment technologies in rural communities in Kenya in a post-implementation setting. Mclaughlin *et al*. (2009) note "that while efficacy describes the potential of an intervention under ideal conditions, effectiveness is a measure of benefit resulting from point-of-use (POU) chlorination under real-world conditions of implementation". For the current study, an observational design was chosen to assess effectiveness (Mclaughlin *et al*., 2009) in order to reduce the bias towards higher microbial reductions in treatment households – a factor for which intervention studies have been criticized for (Mclaughlin *et al*., 2009).

The above-mentioned research questions and study aim will be addressed through the following specific objectives:

The study had five objectives which, though not linearly connected, each contributed to the overall aim of assessing HWT effectiveness in a real-world situation.

1. Assessment of water, sanitation and hygiene (WASH) related knowledge, attitudes and practices of the study households (Chapter 3). This contributes to the overall aim of assessing HWT effectiveness by providing contextual evidence of the setting in which the HWT technologies are being used, post-implementation.
2. Investigation of the perceived value attached to HWT technologies and the likelihood of the adoption of and compliance with household water treatment technologies (Chapter 4). This provides insight into HWT-related user behaviour which may impact on the effectiveness of HWT technologies.
3. Assessment of microbiological water quality changes from source to point-of-use (POU) and the correlation between the water, sanitation and hygiene related (WASH) knowledge, attitudes and practices (KAP) of user households, service providers and observed levels of water quality (Chapter 5). This provides evidence of whether household water treatment is necessary in these communities (as indicated by source water quality) and the effect of the study households' KAP on drinking water quality (as indicated by POU water quality) and therefore provides insights into HWT effectiveness.
4. Assessment of the effectiveness of selected household water treatment technologies (Chapter 6). The microbiological analysis of drinking water quality before and after treatment with the assessed technologies in real-world conditions provides evidence of the *effectiveness* of HWT rather than its *efficacy* which is obtained under controlled laboratory or field conditions.
5. Assessment of the change in risk of bacterial water-borne infections in users of selected HWT technologies, using *E. coli* as an indicator (Chapter 7). This indicates whether there is any potential health benefit to HWT use in real-world conditions at the observed levels of HWT effectiveness.

At the end of the study, a Building a Case (BaC) method previously described by Suter and Cormier (2011) was used to arrive at a conclusion by logically combining the heterogeneous evidence obtained after the five study objectives were addressed. BaC method allows inferences to be made about the interactions between the identified contributors to HWT effectiveness post-implementation from the multiple types of evidence obtained from the laboratory tests and KAP and HWT adoption surveys in this study (Suter and Cormier, 2011).

1.6 Significance of the study

The study's major design premise is based on Cairncross's (1989: 308) view that "though water supply and sanitation are technical interventions, they have significant social dimensions and insofar as they are considered to have public health objectives, they have epidemiological dimensions as well". This study used a multi-lens approach to assess the technical and social aspects of the interventions by combining laboratory-based methods with cross-sectional surveys.

This study makes the following contributions:

a) It is a novel study which provides evidence of the limitations of post-implementation effectiveness of multiple HWT interventions under conditions of typical use.

b) It highlights and clarifies the critical importance of integrating user education with HWT promotion because the KAP survey findings suggest that the people that need HWT most are the ones most unlikely to have the skills and knowledge to operate the technologies effectively.

c) It suggests why HWT is not being adopted on a large scale from the user-perspective by examining the perceived value users attach to various design criteria of the HWT technologies, thus, highlighting the specific gaps that must be closed by manufacturers, promoters, donors and governments to increase adoption and compliance with HWT.

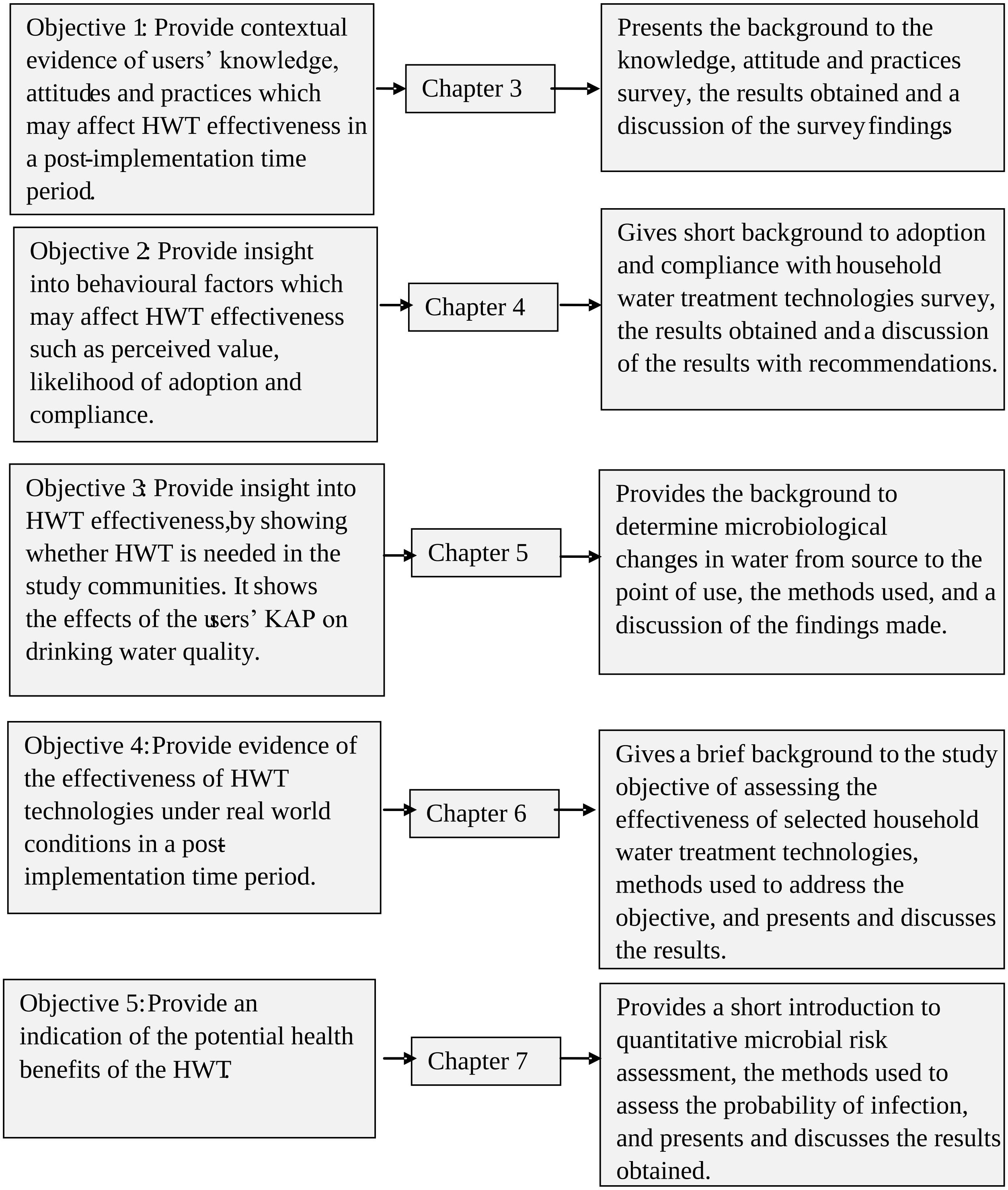
d) It confirms the importance of improved water supply provision, notwithstanding the risks of recontamination after collection, and the importance of HWT even within a context of incorrect HWT use, poor sanitation and hygiene-related HWT-user behaviour.

e) It provides evidence that the term "improved source" does not necessarily mean safe, and that rainwater should not be classified as an improved source.

f) The use of a quasi-experimental study design on pre-existing intervention study sites provides evidence about the efficacy of HWT and addresses the basis of which other studies have been criticised: inadequate controls, artificial study contexts, and biases related to respondent recall, self-reporting and non-blinding (Blum and Feachem, 1983; Schmidt and Cairncross, 2008; Arnold *et al*., 2009).

1.7 Thesis structure

Contributors to effectiveness (Chapter 6) under real-world conditions are: efficacy (Chapter 5), water, sanitation and hygiene related knowledge, attitudes and practices (Chapter 3), perceived value attached to HWT by users (Chapter 4). The effect of these contributors determines the health benefits (Chapter 7) of the HWT technologies under real-world conditions. Consequently, the thesis begins with a summary and consists of eight chapters. Chapter One presents the background to the study and the study rationale in relation to the study questions and objectives. Chapter Two gives an overview of the study area, the general study design, general methods used for sampling, data collection and for water quality analysis. Chapters Three to Seven address the study objectives as shown in Figure 1.2, and Chapter Eight gives the general conclusion and study recommendations. Each of the experimental chapters (Chapters 3–7) consists of an introduction, methods, results and discussions. The references are listed at the end of the thesis. A synopsis of the study is shown in Appendices 1.1–1.3.



Objective 1: Provide contextual evidence of users' knowledge, attitudes and practices which may affect HWT effectiveness in a post-implementation time period.

Presents the background to the knowledge, attitude and practices survey, the results obtained and a discussion of the survey findings

Objective 2: Provide insight into behavioural factors which may affect HWT effectiveness such as perceived value, likelihood of adoption and compliance.

Gives short background to adoption and compliance with household water treatment technologies survey, the results obtained and a discussion of the results with recommendations.

Objective 3: Provide insight into HWT effectiveness, by showing whether HWT is needed in the study communities. It shows the effects of the users' KAP on drinking water quality.

Provides the background to determine microbiological changes in water from source to the point of use, the methods used, and a discussion of the findings made.

Objective 4: Provide evidence of the effectiveness of HWT technologies under real world conditions in a post-implementation time period.

Gives a brief background to the study objective of assessing the effectiveness of selected household water treatment technologies, methods used to address the objective, and presents and discusses the results.

Objective 5: Provide an indication of the potential health benefits of the HWT.

Provides a short introduction to quantitative microbial risk assessment, the methods used to assess the probability of infection, and presents and discusses the results obtained.

Figure 1.2 Thesis structure and objectives

More than a quarter of the global burden of disease is attributable to modifiable environmental risk factors (Rehfuess *et al*., 2009,) a predominant one being inadequate access to safe water and sanitation. Water and sanitation-related diseases are responsible for an estimated 6% of the global burden of disease and 15–20% of the morbidity in the zero to four-year age group (Younes and Bartram, 2001). Diseases attributable to a lack of safe water, sanitation and hygiene lead to 7% of all deaths and 8% of all disability-adjusted live years (DALYs) lost in developing countries, second only to malnutrition, which is responsible for 15% of all deaths and 18% of all lost DALYs (Mara, 2003). The DALY is a measure of disease burden, which combines the burdens of death and disability into a single index (WHO, 2010a).

Water contributes to the disease burden in various ways: it serves as a route of transmission (cholera); as a breeding site of a lifecycle stage of an infective agent (malaria), and as a harbour for an infective agent carrier (schistosomiasis) (Enabor, 1998). In order to make it applicable to disease burdens as well as transmission routes, Cairncross and Valdmanis (2004) adjusted Bradley's categorization of water-related diseases into water-washed, water-borne, water-based and water-related vector diseases based on their transmission routes (Table 1.1). The addition of faecal-disposal diseases which are spread through unhygienic disposal of faeces as a disease group in the classification, and the transmission of many of the same water-borne pathogens through multiple routes, suggests that the focus on one type of environmental health intervention will not interrupt disease transmission (Cairncross and Valdmanis, 2004). Examples of water-borne diseases are typhoid fever and diarrhoea; trachoma is an example of a water-washed disease; schistosomiasis is water-based and malaria is a water-related insect vector disease. This classification does not include non-infectious water-related effects such as drowning or injury, or chemical quality-related diseases such as arsenicosis and fluorosis. Chemical quality-related diseases will be discussed in this chapter to provide a broad context of the risks associated with drinking-water.

1.8.1 Water-related insect vector diseases

This category of diseases is transmitted by vectors which have a stage of their life cycle in or near water: examples are malaria and trypanosomiasis (Cairncross and Valdmanis, 2004).

Malaria

Malaria is a water-related insect vector disease caused by the parasite *Plasmodium spp*. It is life-threatening and causes almost 20% of child deaths in Africa (WHO, 2012). In 2010, an estimated 655 000 people, mostly African children, died from the disease. It can also decrease productivity by as much as 1.3% in countries with a high prevalence and incidence (WHO, 2010b). To combat the problems of malaria, a number of measures are necessary, such as proper sanitation to reduce the standing water that serves as breeding sites of the vector mosquito (UNICEF, 2010b).

Table 1.1 The Bradley classification of water-related infections (Cairncross and Valdmanis 2004).

Transmission route	Description	Disease group	Examples
Water-related insect vector	Transmission by insects that breed in water or bite near water	Water-related insect vector	Dengue, malaria, trypanosomiasis
Water-based	Transmission via an aquatic intermediate host	Water-based	Schistosomiasis
Water–washed (or water–scarce)	Person–to–person transmission because of a lack of water for hygiene	Skin and eye infections	Scabies, trachoma
Water-borne	The pathogen is in consumed water	Faeco-oral	Diarrhoeas, dysenteries, typhoid fever

1.8.2 Water-based diseases

This group of diseases are transmitted through an intermediate host which lives in water. Examples are guinea worm and schistosomiasis (Cairncross and Valdmanis, 2004).

Schistosomiasis

Schistosomiasis (also known as bilharzia) is an example of a water-based disease (Cairncross and Valdmanis, 2004) that affects people engaged in agricultural, recreational and domestic activities when they come into contact with water bodies into which schistome eggs have been excreted (Watts *et al.,* 1998; Kloos *et al.,* 2008). Kloos *et al.* (2008) noted that various studies have found a significant relationship between *S. mansoni* and factors such as the absence of piped water, latrines and showers.

About 200 million people are infected with Schistosomiasis, 20 million of whom suffer severe consequences from the harm caused to critical organs such as the kidneys, liver, intestines, lungs and bladder (UNICEF, 2010b; WHO, 2010b). In addition to the health effects, Schistosomiasis reduces productivity in affected adults and children. Hotez *et al*. (2006) found a significant association between *S. mansoni* and the participation, wages and productivity of workers. They further noted that infected pre-school and school-aged children have significantly higher malnutrition, cognitive impairment and poorer rates of school enrolment, attendance and performance. The infection rates of Schistosomiasis can be reduced by up to 77% by providing adequate levels of environmental health intervention to reduce contact with contaminated surface water (UNICEF, 2010b; WHO, 2010b).

1.8.3 Water-washed diseases

These are diseases that are transmitted by inadequate access to water in terms of quantity rather than quality (Cairncross and Valdmanis, 2004). Their distinguishing feature is that they can be improved by increasing the quantity of water, irrespective of the quality (Cairncross and Feachem, 1993).

Trachoma

Trachoma, an eye infection caused by *Chlamydia trachomati,* is a water-washed disease which is related to inadequate access to water and to poor sanitation and hygiene. These conditions in conjunction with crowded living conditions provide an environment where numerous flies transmit the disease from person to person (WHO, 2010b). It has been estimated that trachoma has resulted in the blindness of six million people worldwide, and the morbidity of 150 million, with women being two to three times more susceptible than men (WHO, 2010b). The provision of adequate water supplies can reduce the infections by 25% (UNICEF, 2009; WHO; 2010b).

1.8.4 HIV/AIDS and water

The WHO (2010b) reported that in 2008, 33.4 million people worldwide were living with HIV/AIDS, and an estimated 2.7 million people were newly infected with the virus. People with compromised immune systems are more vulnerable to the effects of inadequate sanitation and hygiene. The provision of a hygienic environment, safe water and adequate sanitation are thus important in the reduction of infections and the management of the disease (Obi *et al.,* 2006; UNICEF, 2010b). Though all persons are affected by the consumption of unsafe water, the immune-compromised, or babies of HIV/AIDS infected mothers who may choose to bottle-feed, and children under five are at particular risk of diarrhoeal diseases (Dunne *et al.,* 2001). The provision of safe water and latrines close to the point-of-use will contribute to a reduction in the chronic diarrhoea which about 90% of HIV/AIDS patients in Africa suffer from (Obi *et al.,* 2006).

1.8.5 Chemically induced water-related diseases

These are diseases related to the presence of chemical pollutants in water at levels which may be harmful to human health (Cairncross and Feachem, 1993). Examples of these include arsenicosis, fluorosis and methaemoglobinaemia.

Arsenicosis

This chemical quality-related disease is linked to water and sanitation because it is caused by continuous exposure to arsenic in drinking water (WHO, 2001). Arsenicosis has been observed in many countries where the populations have been exposed to arsenic levels in drinking water above the WHO recommended limit of 0.01 mg/l (WHO, 2001; Weir, 2002). The countries include Argentina, Australia, Bangladesh, Chile, China, Hungary, India, Mexico, Peru, Thailand, and the United States of America. Because arsenic is present in the earth’s crust in a variety of compounds (Weir, 2002), the exposure is usually as a result of natural contamination rather than anthropogenic activities. Consequently, Weir (2002) suggested that arsenic has always been present in drinking water in specific locations. Natural sources of arsenic include air (0.02 ug/m^3), surface water (0.05 mg/l), soil (0.05 mg/l), and in vegetation (3–5 mg/kg) (Pimparkar and Bhave, 2010). Examples of anthropogenic sources of arsenic include mine effluents, herbicides, insecticides, pesticides, semiconductors and timber preservative as well as the combustion of fossil fuels deposited from the atmosphere (WHO, 2001; Weir, 2002; Pimparkar and Bhave, 2010). Arsenic levels of between 50–100 µg/kg have also been found in sea food like fish and shrimps (Pimparkar and Bhave, 2010).

Pimparkar and Bhave (2010) note that arsenic occurs in the neutral: zero-valent, trivalent; As(III) and pentavalent: As(V) forms as inorganic or organic compounds. In general, inorganic arsenic is more toxic than the organic form, while the trivalent species is more toxic than the pentavalent and is responsible for the major toxic effects on human health (Pimparkar and Bhave, 2010).

The health effects of arsenic are widespread and severe: for example, Smith and Steinmaus (2011) noted that arsenic is the most lethal environmental toxicant to humans with one in ten people dying from its effects. These health effects may be acute or chronic (Smith and Steinmaus, 2011). Some examples of acute symptoms are vomiting, oesophageal and abdominal pain, bloody "rice water" stools and central nervous system impairment (WHO, 2001; Weir 2002). Symptoms of chronic exposure (which may vary within populations) are bladder, lungs, liver, kidney and skin cancer, peripheral vascular impairment (black foot disease noticed only in the Chinese), skin pigmentation changes and hyperkeratosis (WHO, 2001; Weir, 2002; Smith and Steinmaus, 2011). Smith and Steinmaus (2011) observed that people with arsenicosis have an increased risk of death from cardiovascular disease and noted that arsenicosis has been linked with respiratory diseases, poor pregnancy outcomes, and impaired child development.

The WHO (2001) cautions that drinking water is the greatest source of exposure to arsenic and is thus of grave public health concern. Reduction of exposure may be achieved by reducing the concentrations of arsenic in water or by finding an alternative drinking water source. The recommended primary remedial action is to prevent further exposure through drinking water by changing the water source, though arsenic-rich water can be used for bathing and laundry, because arsenic is not absorbed through the skin (WHO, 2001). If, however, an alternative, safer source cannot be found, efforts should be made to remove the arsenic from the water source (WHO, 2001). However, this is expensive, and the effectiveness of the treatment methods is case specific, depending on factors such as the speciation of the arsenic, the chemical quality of the water in relation to background electrolytes and pH, and scale of treatment plant (Farell, 2002).

Ion exchange, co-precipitation and activated alumina filtration are some of the methods being field-tested for arsenic removal (WHO, 2001). According to WHO (2008), coagulation, ion exchange, precipitation and softening, activated alumina and membrane filtration are able to remove 80% of arsenic from drinking water. Some of these methods are however not feasible options for small-scale treatment systems serving fewer than 10 000 customers (Farell, 2002) and are usually not available as low-cost household water treatment methods promoted in rural African communities. The large contact and settling basin and additional filtration step needed for effective chemical precipitation of arsenic makes it most suitable for large treatment plants which already have these as part of their standard operating processes (Farell, 2002). Though ion-exchange is more suitable than co-precipitation for the removal of arsenic in small treatment plants, it is ineffective for removing As(V) anions, and uncharged As(III) species and uncharged As(V) complexes (Farell, 2002). Membrane filtration is suitable for arsenic removal in small-scale operations, but has the limitation of quick membrane filter fouling if the source water is not pre-treated to remove organics, sediments, iron, manganese and particulate matter (Farell, 2002). Reverse osmosis can effectively reduce arsenic levels to below 0.01 mg/l but has the limitation of removing other ions to very low levels, thus generating large volumes of brine which need to be disposed. Adsorption using activated alumina is more specific to arsenic removal than membrane filtration, because of the formation of a chemical bond between the adsorpent and the arsenic species, though the adsorption may be affected by other ions like silicate and fluorides. The As(III) species is more affected by the completion from other ions, making activated alumina more effective for As(V) removal (Farell, 2002).

Granular ferric hydroxide and zerovalent iron fillings are examples of emerging technologies which possess the advantage over activated alumina of being suitable for user use at the well-head, point-of-use as well as in small-scale treatment plants and of the spent media being easier to dispose (Farell, 2002). Presently, the available low-cost household water treatment options are ineffective for arsenic removal, for example, boiling only concentrates the arsenic in the water, thus worsening the situation (Smith and Steinmaus, 2011) and although PUR is said to remove arsenic in drinking water (WBCSD, 2006) it is not marketed as a treatment for arsenic removal.

The current situation is that the potentially workable solutions need to be adapted and tested for efficacy in each particular setting. In a recent study in South Africa, Mahlangu *et al.* (2012) assessed the ability of the biosand, the bucket and ceramic filters to remove arsenic from water. They found that the three filters were able to remove an average of 50% of arsenic, though their performance was inconsistent and better when water with lower concentrations of arsenic was tested. They noted that a simple ceramic filter made from clay and rice bran is used in rural areas of Bangladesh, though its arsenic removal rates were lower than those found in the South African study (Mahlangu *et al.*, 2012).

Fluorosis

Fluorosis is another example of a chemical quality-related disease with links to drinking water. It is a bone disease caused by the toxic effects of high levels of fluoride in air, water and food; the type due to high levels in drinking water is referred to as endemic fluorosis (WHO/UNICEF, 2005; Xiong *et. al*, 2007). Though low levels of fluoride are beneficial, strengthening teeth and bones, excessive levels above 1.5 mg/l cause damages to human and animal organs such as the liver and kidneys. Though the total number of those affected in the endemic countries is unknown, the number is estimated to be in the tens of millions (UNICEF, 2010b). For example an estimated 100 000 people were affected with fluorosis in a district in Assam, India in the year 2000 (WHO/UNICEF, 2005). Flocculation and electrocoagulation, chemical precipitation, adsorption and ion exchange are some of the methods that are used for defluoridation (Gong *et al*., 2012). Adsorbents such as amorphous alumina, activated carbon, calcite, clay, charcoal, rare earth oxides and activated alumina have been used in defluoridation (Tripathy *et al*., 2006). However, most of these adsorbents cannot reduce fluoride levels to below 2 mg/l (Tripathy *et al*., 2006). Activated alumina is however able to remove 70% of fluoride at a pH of 7 (Tripathy *et al*., 2006).

1.8.6 Water-borne diseases

Water-borne diseases are transmitted when the water-borne pathogen is ingested from water contaminated with faeces or urine from infected persons **(**Cairncross and Valdmanis, 2004)**.** These diseases may also be faeco-orally transmitted through dirty hands, food and drinking water. Though often self-limiting, some of the water-borne pathogens like *Vibrio cholerae*, hepatitis E virus and *Escherichia coli* O157:H7 have high mortality rates (OECD/WHO, 2003)**.** Furthermore, water-borne pathogens have been associated with chronic diseases: Coxsackie B4 virus with diabetes; echovirus with myocarditis; *Campylobacter* spp. with Guillain-Barrè syndrome and *Klebsiella* sp. with reactive arthritis **(**OECD/WHO, 2003). Classical examples of water-borne diseases are typhoid fever, cholera and diarrhoea.

Typhoid fever

Typhoid fever is a bacterial disease, caused by *Salmonella typhi* which is ingested from food or contaminated water. Twenty-two million cases occur annually with about 200,000 deaths (Parry, 2005). Preventive measures for typhoid include the provision of improved, water and sanitation, food hygiene and good personal hygiene practices such as hand washing with soap (UNICEF, 2009; WHO, 2010b).

Cholera

Cholera is an acute intestinal infection caused by the facultative bacteria *Vibrio cholerae*, found in estuarine and freshwater environments. It is transmitted by food or water contaminated with faeces (Reidl and Klose, 2002; Parry, 2005; Righetto *et al*., 2011). Characteristically, it leads to watery diarrhoea known as “rice water stool” which, if untreated, can cause death through the loss of essential fluids. However in some cases, the disease is mild and the diarrhoea ends within one week (Parry, 2005). Cholera is a world-wide problem, with major consequences in developing countries, as a result of inadequate hygiene and medical facilities (Reidl and Klose 2002; UNICEF, 2010b). The majority of cases between 1997 and 2000 occurred in Eastern and Southern Africa (UNICEF, 2010b). Kigotho (1997) noted that within a period of 10 days, 140 people died in the cholera epidemic of 1997, which spread to Tanzania from Kenya. In 2002, more than 120 000 cholera cases were reported worldwide, while in 2008, 3 091 cholera cases occurred in Kenya (WHO, 2010b), with outbreaks still being experienced as recently as 2009. Hygienic food, clean water and good personal hygiene are effective preventive actions against cholera (WHO, 2010b).

Diarrhoea

The UNICEF (2010b) emphasizes that diarrhoea which is caused by contaminated food and water is the most critical water and sanitation-related disease (WHO, 2009). Diarrhoeal diseases are the second leading cause of death in children under five years of age (WHO, 2009), and cause about 1.9 million deaths of under-fives or 19% of the total child deaths globally (Boschi-Pinto *et al*., 2008). Repeated episodes of diarrhoea increases children's vulnerability to malnutrition and other illnesses. Two children under the age of five die every minute in developing countries (Mara, 2003) and in WHO African and South–East Asia regions[1] combined, accounting for 78% (1.46 million) of all diarrhoea-related deaths amongst children in the developing world (Table 1.2), about three-quarters of which are concentrated in 15 developing countries (Boschi-Pinto *et al*., 2008). Though Kenya is not one of these countries, its burden of diarrhoeal disease is high, with diarrhoea being the second highest contributor to mortality and morbidity among children under five years of age (KNBS, 2009a).

From the foregoing, it is clear that inadequate access to water supply and sanitation has a severe impact on human health, particularly in the developing world where mortality rates are higher than those of developed countries (Sobsey *et al.,* 2008; Rehfuess *et al.*, 2009). Though the burden of water and sanitation-related disease is higher in the developing world and 37% of the 884 million people with inadequate access to safe water live in sub-Saharan Africa (WHO/UNICEF 2010), it must be stressed that these water-related illnesses are not restricted to developing countries. Outbreaks caused by contaminated drinking water or recreational activities occur annually in developed countries including Organisation of Economic Cooperation and Development member countries (Younes and Bartram, 2001; OECD/WHO, 2003). Outbreaks, such as the 1993 occurrence of 400 000 cases of cryptosporidiosis in Milwaukee, USA and a

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[1] WHO defined regions are African Region (AFR); Region of the Americas, South East Asia Region, Eastern Mediterranean Region and Western Pacific Region (Boschi-Pinto *et al.,* 2008)

1994 outbreak in Nevada, USA, highlighted the importance of microbiological water quality in both developed and developing countries (OECD/WHO, 2003).

The macro-economic implications of diarrhoea

The macro-economic implications of diarrhoea in developing countries are related to the expenses incurred for treating preventable diseases, and the long-term effects of the reduced productivity of workers who suffered cognitive function loss because they were affected with diarrhoea in childhood (Mara, 2003; Dungumaro, 2007). The short-term macro-economic effects of water and sanitation-related diseases have also been quantified. For example, the Water and Sanitation Program of the World Bank estimates that poor sanitation costs Kenya US$324 million annually, which is equivalent to 0.9% of the national GDP (WSP, 2012).

In addition to quantifying the economic effects of the water and sanitation-related disease burden, the short-term gains of improved water and sanitation access have also been quantified. Hutton and Haller (2004) carried out a global evaluation of the cost and benefits of improved water and sanitation. The criteria they used to quantify the gains are related to time savings from improved access to water and sanitation facilities, such as increased productivity from reduced illness, savings in treatment costs due to reduced diarrhoeal diseases, and the value of the prevented deaths. The study found that all types of water and sanitation improvements in all regions of the world are cost-beneficial, and that in developing regions, the return on a US$1 investment was in the range of US$5 to US$28. A time savings of 320 million productive days is gained each year as a result of better health, 20 billion working days per year are gained from more closely situated water supply and sanitation services, and 272 million school-attendance days are gained from the resultant better health (UNICEF, 2009). Mara (2003), however, stressed that the long-term macro-economic implications of diarrhoeal disease for developing countries, such as its association with poor cognitive function in early childhood, are yet to be recognized. He postulated that until faeco-oral diseases in childhood are reduced, developing countries will continue to produce poorly educated workers who are unable to realise their full potential.

Table 1.2 Countries accounting for three-quarters of deaths due to diarrhoea in the developing regions of the world (Clark and Gundry, 2004).

Country	WHO Sub region*	Deaths due to diarrhoea (thousands)
India	SEAR: D	535
Nigeria	AFR: D	175
Democratic Republic of the Congo	AFR: E	95
Ethiopia	AFR: E	86
Pakistan	EMR: D	77
China	WPR: B	74
Bangladesh	SEAR: D	69
Afghanistan	EMR: D	65
Indonesia	SEAR: B	39
Angola	AFR: D	34
Niger	AFR: D	33
Uganda	AFR: E	28
Myanmar	SEAR: D	26
United Republic of Tanzania	AFR: E	25
Mali	AFR: D	24
Total of 15 countries		1384

*AFR, WHO African Region; AMR, WHO Region of the Americas; EMR, WHO Eastern Mediterranean Region; SEAR, WHO South–East Asia Region; WPR, Western Pacific Region. WHO sub regions are defined on the basis of levels of child and adult mortality: A, very low child and very low adult mortality; B, low child and low adult mortality; C, low child and high adult mortality; D, high child and high adult mortality; E, high child and very high adult mortality.

1.9 Water, sanitation, hygiene and disease in sub-Saharan Africa

Table 1.2 indicates that eight of the fifteen countries that account for three–quarters of diarrhoeal mortality globally are in sub-Saharan Africa. Furthermore, in 2008, cholera epidemics in more than a dozen sub-Saharan African countries resulted in about 100 000 illnesses and more than 1 000 deaths (Mintz and Guerrant, 2009). In 2005, Africa reported a cholera incidence which was 95 times that of Asia and 16 600 times that of Latin America and in 2007, a cholera incidence which was seven times that of Asia (Mintz and Guerrant, 2009). In Kenya, cholera outbreaks have also been a regular annual occurrence until 2010. Records of the Disease and Surveillance Response Department from 2007–2010 and stakeholder perceptions indicate that intervention by The Ministry of Public Health and Sanitation (MoPHS) in selected districts in Western Kenya has contributed to a sharp decline in cholera occurrence in these districts. In Kenya, diarrhoea is the second main contributor to mortality and morbidity among children under 5 years of age. The Kenya Demographic Health Survey of 2008 estimated that 20% of all deaths in Kenya are attributable to diarrhoeal diseases (KNBS, 2009a). Kenya loses $2.7 million annually from the lost productivity and accessing health care whilst sick (WSP, 2012).

Inadequate water and sanitation infrastructure and unhygienic living conditions are responsible for the high incidence of cholera and other water and sanitation related diseases that thrive in poor environmental conditions in Africa (Mintz and Guerrant, 2009). According to the Joint Monitoring Program, sub–Saharan Africa has the lowest drinking water and sanitation coverage of any region. The majority (94%) of people who use surface water live in this region and almost half (45%) of the inhabitants use shared or unimproved sanitation facilities (JMP, 2012).

1.10 Disparities in safe water, sanitation and hygiene provision

Universal access to safe water and sanitation has been promoted for decades as essential for disease reduction and prevention (Clark and Gundry, 2004). It is pertinent to note that the impact of inadequate access to water and sanitation, though not restricted to developing countries is borne primarily by developing countries due to economic, social and geographic disparities, and that such impact extends beyond the presence or absence of disease (Younes and Bartram, 2001).

The global effort to provide universal access to safe water and sanitation is anchored in the Millennium Development Goal (MDG) 7 target 10, which aims to halve the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015 (UN, 2010). The WHO/UNICEF Joint Monitoring Program (JMP) for the water supply and sanitation sector is the body tasked with the global responsibility for reporting on the MDG 7 targets. Reasonable access was defined by the JMP as access to at least 20 litres per capita per day from a source not more than a kilometre from the user's dwelling (Cairncross and Valdmanis, 2004), using the proportion of people using improved drinking water as the indicator for access (WHO, 2010a).

The JMP defines an improved water source as “one that by nature of construction or through active intervention, is protected from outside contamination, in particular from contamination with faecal matter”. Examples of improved water sources are: household connection, public standpipe, borehole, protected dug well, protected spring, and rainwater (Table 1.3). The JMP defines an improved sanitation facility as “one that hygienically separates human excreta from human contact” and Table 1.4 gives an indication of the variety of improved and unimproved sanitation facilities.

Table 1.3 Improved and unimproved water sources WHO/UNICEF (2010).

Source category	Source type
Improved drinking water sources	1. Piped water into dwelling, yard or plot 2. Public tap or standpipe 3. Tubewell or borehole 4. Protected spring 5. Rainwater collection
Unimproved drinking water sources	1. Unprotected dug well 2. Unprotected spring 3. Cart with small tank or drum 4. Tanker truck 5. Surface water (river, dam, pond, lake, stream)

The MDG 7 target implies a commitment to raising the global access to safe drinking water from 77% in 1990 to 88.5% by 2015 and raising the global access to improved sanitation from 49% in 1990 to 75% by 2015 (WHO, 2010a). However, the term ‘coverage’ does not mean that the supply meets the requirements for health improvement in in terms of adequacy, reliability, convenience, acceptability or use of the water supply (Younes and Bartram, 2001). Sub-Saharan Africa faces the greatest challenge in increasing the use of improved drinking-water facilities because 37% of the 884 million people who still use unimproved sources live in this region (WHO/UNICEF, 2010). The implications of poor access are heightened by the report’s warning about the challenges of measuring water safety indicators at household level on a global scale. This implies that the improved coverage figures may not be an actual reflection of adequacy in terms of the quality or the safety of the water being consumed. Therefore sub-Saharan Africa was the focus of this study, and Kenya was the site of field data collection.

Table 1.4 Improved and unimproved sanitation facilities (WHO/UNICEF, 2010).

Source category	Source type
Improved sanitation	1. Flush or pour-flush to; a. Piped sewer system b. Septic tank c. Pit latrine 2. Ventilated Improved Pit (VIP) Latrine 3. Pit latrine with slab 4. Composting toilet
Unimproved sanitation	1. Flush or pour-flush to elsewhere i.e. not to; piped sewer system, septic tank, pit latrine 2. Pit latrine without slab, open pit 3. Bucket 4. Tanker truck 5. Hanging toilet or hanging latrine 6. Shared facilities of any type 7. No facilities, bush or field

Kenya is an example of a country where coverage does not necessarily translate into access to safe water. It has a total improved drinking water coverage and improved sanitation coverage of 59% and 27% respectively, but because of the country's aging and poorly maintained water supply and sanitation infrastructure, the population's water demand is not sufficiently addressed in terms of quality or quantity (UNESCO, 2006; WHO/UNICEF, 2010). South Africa is another example with a total drinking water coverage of 91% and improved sanitation coverage of 77%. However, provision of safe drinking water remains a challenge to many South African municipalities with only 38 out of the 787 water supply systems assessed attaining the Blue Drop certification status in 2010 (DWA, 2010; WHO/UNICEF, 2010). The Blue Drop status represents the Water Services Authorities' efficiency and effectiveness in drinking water management.

In addition to the disparity between coverage and water safety, the challenge of increasing access to improved water in terms of quantity as well as quality is further complicated by disparities in provision which may be geographical (between urban and rural), socio-economic (between the poor and more economically well-off), or in relation to the disproportionate focus on water in comparison with sanitation.

With regard to the geographical disparity, the JMP's 2010 report noted that 84% of the world's population who lack an improved drinking water source live in rural areas, while the use of improved drinking water sources in urban areas is almost double the use in rural areas of sub-Saharan Africa and Oceania (WHO/UNICEF, 2010). Table 1.5 indicates that Kenya, for example, has a total improved drinking water coverage of 83% in the urban areas compared with 52% in the rural areas, while South Africa has a total improved drinking water coverage of 99% and 78% in the urban and rural areas respectively (WHO/UNICEF, 2010).

Another type of disparity is socio-economic, which is illustrated on a global level by the observation that the richest quintile is more than twice as likely as the poorest quintile to use an improved drinking water source and that the poorest quintile is sixteen times as likely to practice open defecation (WHO/UNICEF, 2010).

In Kenya, the poor, who form approximately 70% of the population bear the brunt of inadequate access to safe water and most of them obtain water for domestic purposes directly from rivers, lakes, dams, streams and impoundments. The urban poor in peri-urban areas are also affected as they rely on water vendors who deliver water of uncertain quality (UNESCO, 2006). A socio-economic disparity is also observed in South Africa despite the constitutional recognition that sufficient access to water which is not harmful to health or the environment is a basic human right (RSA, 1996). Table 1.5 indicates that 22% of those living in rural areas who are predominantly poor, use unimproved water sources compared to only 1% of those who live in the urban areas (WHO/UNICEF, 2010).

From the above, it is clear that there is a disparity in water and sanitation access which is highlighted by the warning by WHO/UNICEF (2010) that, though progress is being made towards improving access to safe drinking water, the progress in access to basic sanitation is insufficient to achieve the MDG target of 2015 to halve the proportion of people without sustainable access to safe drinking-water and basic sanitation. For example, South Africa, has a total coverage of 91% and 77% for improved water and sanitation respectively, while Kenya's, total coverage figures are 59% and 31% for improved water and sanitation respectively (WHO/UNICEF, 2010). The preceding discourse highlights the concern that the rural and urban poor, who often make up a sizeable portion of a country's populace, are still disproportionately underserved in terms of access to safe water and sanitation and consequently, the rural and urban poor suffer most from the resultant morbidity and mortality.

Table 1.5 Access to safe water and sanitation in selected countries (WHO/UNICEF; 2010).

Country	**Population in 2008 (thousands)**	**Percentage (urban population)**	**Use of Sanitation Facilities (% of population)**				**Use of Drinking Water Sources (% of population)**			
			Urban	Rural	Total	No. who gained access between 1990 – 2008 (thousands)	Urban	Rural	Total	No. who gained access between 1990 – 2008 (thousands)
Australia	21 074	89	100	100	100	3 983	100	100	100	3 983
Angola	18 021	57	86	18	57	7 606	60	38	50	5 172
Botswana	1 921	60	74	39	60	666	99	90	95	568
Cameroon	19 088	57	56	35	47	3 222	92	51	74	8 009
Canada	33 259	80	100	99	100	5 558	100	99	100	5 558
China	1 337 411	43	58	52	55	267 319	98	82	89	425 096
Denmark	5 458	87	100	100	100	318	100	100	100	318
Egypt	81 527	43	97	92	94	35 030	100	98	99	28 706
Ethiopia	80 713	17	29	8	12	7 754	98	26	38	22 461
Ghana	23 351	50	18	7	13	1 988	90	74	82	11 065
Iceland	315	92	100	100	100	61	100	100	100	61
India	1 181 412	29	54	21	31	211 049	96	84	88	418 886
Iraq	30 096	67	76	66	73	-	91	55	79	9 132
Kenya	38 765	22	27	32	31	5 925	83	52	59	12 795
Lesotho	2 049	25	40	25	29	82	97	81	85	765
Malawi	14 846	19	51	57	56	4 344	95	77	80	8 096
Mexico	108 555	77	90	68	85	37 226	96	87	94	31 149
South Africa	49 668	61	84	65	77	12 890	99	78	91	14 699

1.11 The importance of water, sanitation and hygiene

Clark and Gundry (2004) noted that the impact of improved water supply, sanitation and hygiene on health is related to various roles of water which are: a fundamental resource for survival, essential to food preparation and drinking, both a route of contamination and a barrier to disease.

Though Hutton and Haller (2004) noted that adequate access to water has health and non-health benefits which are directly or indirectly related to human well-being, Clark and Gundry (2004) failed to highlight the non-disease related health impact of inadequate water and sanitation. Younes and Bartram (2001) classified the benefits of improved water and sanitation into non-health and health benefits. The health benefits of water are linked to the reduced morbidity and mortality from water-borne and water-based diseases, while the indirect health-related effects are the improved quality of life and savings on health care costs (Younes and Bartram, 2001). The non-health benefits are those related to the time saved as a result of more accessible water and sanitation facilities, which can be used for education and other productive activities (Younes and Bartram, 2001). However donor agencies such as the Department of International Development (DFID), The World Bank, DFID and The EU recognise the non-health benefits of clean water and sanitation and prioritise improving access to these interventions in their strategies for poverty reduction and sustainable development. Rukunga *et al.* (2002) noted that the inadequate access to water and sanitation has implications for poverty alleviation, environmental management and gender as well as child and adult health. The brunt of the inadequate access is usually borne by the rural poor in developing countries, who usually do not have the infrastructure and resources to ameliorate the effects of inadequate water supply and sanitation (Hope, 2006).

There is no conflict between the school of thought that highlights the impact of inadequate water, supply, sanitation and hygiene in relation to its effect on the environment, livelihoods of the poor and potential for poverty reduction and the school of thought that relates the impact of inadequate access to water, sanitation and hygiene to health. For example, Cairncross and Valdmanis (2004) maintain that the reduction of diarrhoeal diseases is the major health benefit of improved water supply, sanitation and hygiene. The two views agree that, if health is considered from the perspective of WHO’s globally accepted definition of health it is “a state of complete physical, mental and social wellbeing, and not merely the absence of disease or infirmity” (WHO, 1946:100).

1.12 Addressing inadequate water supply, sanitation and hygiene

The global community recognizes the disease and non-disease related impact of inadequate water and sanitation and stresses that providing adequate safe drinking water and hygienic sanitation facilities is crucial as these environmental health interventions play an essential role in the fight against poverty and hunger (MDG 1); primary education (MDG 2); gender equality and women empowerment (MDG 3); child mortality (MDG 4); maternal health (MDG 5); HIV/AIDS and malaria (MDG 6); environmental sustainability (MDG7) and developing global partnerships (MDG 8) (WHO, 2010a).

Despite the concerted efforts and considerable sector knowledge about the role that water, sanitation and hygiene play in disease transmission, progress towards achieving the sector goals is slow. An estimated 2.5 billion and 884 million people still do not use improved sanitation and water respectively ((WHO/UNICEF, 2010). Various reasons have been given for the slow progress in delivery of these environmental health interventions and achieving the intended health benefits, some of which, according to Mara (2003) and Rehfuess *et al.* (2009) include a lack of clarity about roles and responsibilities and the low involvement of the health sector in the delivery of water and sanitation the use of inappropriate technologies and the absence of professionals to integrate water and sanitation delivery with health.

While it is crucial that the ‘sector’ addresses the institutional, social and capacity issues raised by Mara (2003) and Rehfuess *et al.* (2009), a successful strategy for providing a safe water supply and adequate sanitation must be based on selecting the right type of intervention. In this, ‘the sector’ must bear in mind that focusing on one type of environmental health intervention will not interrupt transmission of disease (Mara, 2003), firstly, because water causes disease in various ways (Enabor, 1998; Younes and Bartram, 2001); secondly, many of these water-borne pathogens are transmitted through multiple routes (Mara, 2003; Cairncross and Valdmanis, 2004), thirdly the accepted categorisation of water and sanitation-related diseases into water-washed diseases, water-borne, water-based, water-related vector diseases and faecal-disposal diseases suggests that different environmental interventions are needed to address the different routes of transmission.

1.12.1 The effectiveness of water supply, sanitation and hygiene interventions

According to Fewtrell and Colford (2004) and Clasen *et al.* (2007b), water, sanitation and hygiene-related environmental health interventions can be classified into the following five groups:

a) Water supply: these are interventions which provide an improved water source at the community or household level, using stand-alone sources or household connections.
b) Sanitation (hardware): refers to facilitating improved human faecal disposal through a sanitary means such as improved latrines.
c) Water quality interventions or "enhanced water supply": provides the means to improve microbial water quality by treatment or/and safe storage at the source or point-of-use.
d) Hygiene: promoting personal hygiene practices, such as hand washing, and food and water hygiene within the household and community.
e) Multiple interventions: those which use a combination of the various interventions to improve the environmental health of the targeted population.

Various systematic reviews of impact studies have been carried out to assess the effectiveness of environmental health interventions in order to guide the selection of those with the greatest impact on water-borne disease reduction: Esrey *et al*. (1985); Esrey *et al*. (1991); Gundry *et al*. (2004); Fewtrell and Colford (2004); Sobsey *et al.* (2008); Clasen *et al.* (2007b) and Waddington *et al.* (2009).

These reviews disagree, sometimes considerably, about the comparative effectiveness of the various groups of environmental health interventions shown in Table 1.6. Esrey *et al*. (1985) found the combination of water quality with water availability to be the most effective intervention in reducing diarrhoea, but in a subsequent study in 1991, found hygiene to be the most effective single intervention. Esrey *et al.* (1985) and Esrey *et al.* (1991) reported that water quality improvement was the least effective of the interventions with median reductions in diarrhoea of 1 and 17% respectively. In contrast, Clasen *et al.* (2007b), who reviewed 42 point-of-use water quality interventions carried out in countries such as Ghana, South Africa, Zimbabwe and Bangladesh, observed a much higher effectiveness of 42% reduction in diarrhoea, which was consistent with the observation by Waddington *et al.* (2009), who also reported a 42% reduction in diarrhoea morbidity as a result of water quality interventions.

Reviewers also differed in their observations about the effect of combined water, sanitation and hygiene intervention in reducing diarrhoea. For example, although Esrey *et al.* (1985) found that the combination of water quality and water availability had a greater impact than either of these interventions separately, Clasen *et al.* (2007b) found no evidence to justify costs incurred in combining interventions on the basis of the expected health benefits. This contradicts the observations by Waddington *et al.* (2009) who, after reviewing 65 impact evaluations and 71 interventions, reported a 57% reduction in childhood diarrhoea with a combination of water supply, sanitation and hygiene interventions (Table 1.6).

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Table 1.6 Impact of WASH interventions on diarrhoea morbidity (Esrey *et al*., 1985; Esrey *et al*., 1991; Clasen *et al*., 2007b; Waddington *et al*., 2009).

Author	**Diarrhoeal morbidity reduction by interventions (%)**							
	Water quality	Excreta disposal	Water availability	Water quality and availability	Water and sanitation	Hygiene	Water quality, sanitation and hygiene	Combined interventions (unspecified)[a]
Esrey *et al.* (1985)	16	22	25	37	N.D	N.D	N.D	N.D
*Esrey *et al.* (1991)	17 (15)	22 (36)	27 (20)	16 (17)	20 (30)	33	N.D	N.D
Clasen *et al.* (2007b)	42	N.D	N.D	N.D	N.D	N.D	N.D	N.D
Waddington *et al*. (2009) (Pooled results)	42	37	ineffective	N.D	N.D	31	N.D	38
Waddington *et al*. (2009) (subgroup results)	44 (point-of-use)	39	21 (POU water supply)	N.D	N.D	31	N.D	38
	34 (point-of-use with storage device)	31 (sewer)	N.D	N.D	19 (water supply+ sanitation + hygiene)	37 (soap provision only)	N.D	N.D
	21 (source water quality)	34 (latrine provision)	N.D	N.D	N.D	27 (education without soap provision)	57 (water quality + sanitation + hygiene)	-

[a] Combined interventions but the types are not specified in the reviewed studies; All reductions are shown as pooled effects except for Esrey *et al*., 1985; Esrey *et al*., 1991 which report median effects; N.D: Not Done; POU: point-of-use; *Figures outside bracket show median reduction from rigorous studies and inside bracket shows reduction from all studies.

1.12.2 Water supply versus household water treatment

Notwithstanding the systematic reviews, various options to ensure that consumers obtain the intended health benefits from water have been proffered. From a health-based perspective, Stevenson (2008) advised that the best option for ensuring safe drinking water from the source to the point-of-consumption is the provision of water that is reticulated to the household level, an option which he further noted is available to 99% of the high-income, developed country populace. Clasen & Cairncross (2004) agreed that the microbiological quality of water can be maintained by providing water through reticulated systems because it ensures residual disinfection and safe storage.

Some authors, however, disagree with Stevenson (2008) on the feasibility of piped distribution to the household level as a short-term strategy. For example, Clasen and Edmonson (2005) point to the length of time needed to provide infrastructure to the 1.1 billion people that are currently unserved. Stevenson (2008) and Peter-Varbanets *et al*. (2009) base their dissension on the prohibitive cost (manpower, supplies, equipment, logistics and support) of providing and maintaining piped water to unserved and often dispersed rural populations in developing countries.

Rather than providing piped water supplies, some authors are of the opinion that point-of-use water treatment might be a more cost-effective option. For example, Hutton and Haller (2004) estimated the cost of piped water provision/capita/day in Africa as $12.75 in comparison to $0.33 dollars for household water treatment. Peter-Varbanets *et al*. (2009) also advises that point-of-use treatment systems might be a more viable option, since only 2–5% of tap water is used for domestic consumption. Mintz *et al*., (2001) and Peter-Varbanets *et al*. (2009) also consider household water treatment and storage as the appropriate option because it is the only choice available to disadvantaged households in certain situations, for instance, where a local authority is unable to provide centralized or even small-scale water treatment plants as a result of financial or capacity challenges, households must find a way to treat their water or else bear the health-related consequences (Mintz *et al*., 2001 and Peter-Varbanets *et al*., 2009).

Other authors suggest a combination of approaches rather than choosing between household water treatment and piped-borne water supplies. Clasen and Bastable (2003) agree with Clasen and Cairncross, (2004) that promoting low-cost household water treatment interventions will help to protect the microbial safety of water till it gets to consumers. They also suggest promoting improved transport, collection and storage practices by users, which in their view will inculcate the necessary health and hygiene supportive behavior by users as well as their use of safe vessels for storage.

Still other researchers are of the view that both options are necessary: improved water sources and household water treatment. Lantange *et al.* (2006) considers HWT options necessary in the short-term while the longer-term water supply is being put in place. Clasen *et al.* (2007b) observed that improved water supply, rather than household water treatment may have greater health benefits in the long-term because of its ability to improve the quantity of water available to the user, but stress that even when the safe water supply target has been met, a considerable number of people will still be vulnerable to water-borne diseases. Clasen (2010) cautions that, because household water treatment does not increase access to water, the proposed inclusion of HWT in MDG 7, the safe water target, is not advisable as it will encourage governments to divert much-needed resources for water supply into other areas.

The WHO (2007:9) supports household water treatment in the short-term and notes that "household water treatment is able to improve the quality of stored household water quickly, reducing the risks of diarrhoeal disease and death". The argument about water supply versus household water treatment seems to have come full circle because some researchers feel that treatment at the household level is necessary because the stand-alone water supply technology used in rural African communities is open to recontamination. Mintz *et al.* (2001), Clasen and Bastable (2003), Clasen and Edmonson (2005) cite the attendant health costs of water-related diseases when piped supplies cannot be fully reticulated to households; other authors base their support of household water treatment on the reported inability of decentralized community-level systems to guarantee water that is consistently safe at the point-of-use (Mintz *et al.*, 2001; Clasen and Bastable, 2003; Wright *et al.*, 2004; Luby *et al.*, 2008).

1.12.3 Water supply technology and the relationship with household water treatment

Zwane and Kremer (2007) argue that although water supply is a health-related intervention, not all improved water supply technologies provide the intended health benefits. They point out that although piped water supplies have proved to reduce diarrhoeal transmissions, the sector still needs to provide evidence that stand-alone improved water supplies do the same. Cairncross and Feachem (1993) and DFID (1998) also observe that collecting water from outside the home affects health directly and indirectly. From the foregoing, it is clear that there is a school of thought which maintains that the strategy for reducing the disease burden of diarrhoea by using decentralised water sources such as boreholes, standpipes, wells and springs reduces the microbiological quality of the water after collection, thus negating the intended health benefits (Wright *et al.*, 2004; Zwane and Kremer, 2007).

Younes and Bartram (2001) disagree that decentralised water supplies are the only types of water supply technologies that are open to contamination. They point out that though the available evidence indicates that about a third of diarrhoea cases result from exposure to unsafe drinking water, such exposure is not restricted to unimproved or stand-alone improved sources. This is because the quality of piped water may also deteriorate because of regrowths of bacteria or recontamination within the distribution system (Younes and Bartram, 2001), or because old infrastructure sometimes used for distribution of piped water makes the water susceptible to contamination from the outside (Moe and Rheingans, 2006).

Clasen *et al.* (2007b) argued that, though external factors impact on the quality of water produced in a reticulated system, more factors affect a non-reticulated system, thus suggesting that water supply technologies which involve collection outside the home are more likely to be contaminated in the process of transportation and storage (Cairncross and Feachem, 1993; DFID, 1998 and Gleick, 2002). Younes and Bartram (2001) concur, acknowledging that microbiological contamination of improved sources is mainly a problem of small community water supplies.

From the foregoing it is apparent that even though piped water supplies are subject to contamination, the community level interventions which according to Clark and Gundry (2004) have been the dominant water supply technology in rural communities for the past 20 years are more predisposed to recontamination unless community involvement is improved (Jagals *et al*., 2003) and users of such water supplies takes steps to treat the water at the household level (Mintz *et al*., 2001; Wright *et al*., 2004).

1.12.4 Household water treatment technologies

Household water treatment (HWT) technologies refer to any device that is used to treat water at the point-of-use which may be the home or elsewhere, for example schools and hospitals. They are also known as point-of-use or point-of-entry systems (WHO, 2008). Point-of-use technologies treat only the portion of water intended for drinking which is about 8 l for a household of four persons, while point-of-entry technologies treat all the water that enters a household (Peter-Varbanets *et al*., 2009). Point-of-use technologies and source-based treatment plants employ the same approaches to water treatment, though point-of-use-systems may incorporate some processes that are not used in centralized water treatment (WHO, 2008). POU water treatment systems may use a single or combined treatment process to purify water. For example, microbiological water purifier units attempt to remove water-borne pathogens using filtration, while PUR combines flocculation and chemical disinfection (Gerba and Naranjo, 2000).

The approach to water treatment can be broken down into three types: (a) chemical treatment (assisted sedimentation, ion exchange, chemical disinfection, coagulation, flocculation and precipitation), (b) physical removal of pathogens (filtration including membrane and ceramic filters, sedimentation and settling), and (c) UV radiation and heat (boiling, SODIS, solar radiation) (Clasen and Cairncross, 2004 and Peter-Varbanets *et al*., 2009).

(a) Chemical Disinfection

Chlorination with safe storage

Disinfection aims to destroy pathogenic organisms (Geldenhuys, 2006) and chlorination is a process which has been used since the early twentieth century to disinfect public water supplies (Cutler and Miller, 2005). Chlorine-based disinfectants are historically the most popular type of disinfectants (Geldenhuys, 2006). Although centralized urban water treatment systems treat water with chlorine gas, chlorine is used in household water treatment in forms such as sodium hypochlorite, calcium hypochlorite, flocculant-disinfectant (combination of calcium hypochlorite and ferric sulphate) and sodium dichloroisocyanurate (NaDCC) (Clasen and Edmonson, 2005; Clasen *et al.*, 2006).

The mechanism of action of the various chlorine-based disinfectants is similar, though they differ in form and amount of active ingredient, which gives them different advantages and disadvantages.

They all disinfect water by undergoing reactions which release free available chlorine in the form of hypochlorous acid (HOCl), the active microbiocidal agent (Clasen and Edmonson, 2005). The efficacy of chlorine is dependent on its concentration, contact time, pH of the water and temperature. A few mg/l of chlorine can reduce water-borne pathogens by more than 4 log reductions at an optimal drinking water pH of 8 and contact time of 30 minutes (Clasen and Edmonson, 2005; WHO 2008).

Sodium hypochlorite

The first large-scale promotion as a point-of-use intervention was carried out by the Pan American Health Organisation and Center for Disease Control in the nineties (Lantagne *et al*., 2006). Known as the Safe Water System (SWS), it was part of an integrated package consisting of three components, namely sodium hypochlorite (household bleach), a safe storage vessel for treated water, and health education and hygiene. The SWS project in Kenya started in 2000 with a CARE Kenya pilot project in Nyanza province. Marketed as Waterguard, the 1% sodium hypochlorite solution can be added to water directly to render it safe for drinking (Alekal, 2005). The recommended dosage is 1.875 mg/l for water of low turbidity (< 10 NTU) and 3.75 mg/l for water of higher turbidity i.e. 10–< 100 NTU (Alekal, 2005; Lantagne *et al*., 2008). This dosage can be met by adding one capful of Waterguard to 20 l of water, stirring the water and waiting for 30 minutes before consumption (Lantagne *et al.*, 2008). Waterguard is sold in Kenya by Jet Chemicals Ltd, Nairobi (Alekal, 2005); 150 ml of sodium hypochlorite costs 20 KES ($0.23 at the rate of 85 KES: $1).

The mechanism of action of sodium hypochlorite is the same as that described in the preceding section for hypochlorous disinfectants.

Waterguard has three limitations: the distinct taste it imparts to treated water, particularly when used in water with high organic content; its reduced efficacy in highly turbid water and against cyst-forming protozoa such as *Giardia* and *Crysptosporidum*, as well as the possible carcinogenic effects of the chlorination of turbid water (Mintz *et al.*, 2001; Rangel *et al.*, 2003; Crump *et al.*, 2004; Trevett *et al*., 2005; Lantagne *et al*., 2006; CDC, 2006,).

Waterguard's advantages are: the chlorine residual it leaves in treated water which helps to prevent recontamination; its ease of monitoring in treated waters; ease of use; proven efficacy against bacteria and viruses, and its low cost (Mintz *et al.*, 2001; Crump *et al.*, 2004; CDC, 2006; Lantagne *et al.*, 2006).

Calcium hypochlorite

This is a hypochlorite-based disinfectant which is sold as pellets or tablets (CDC, 2006). Its disadvantages include the variation in the number of active ingredients the various forms of calcium hypochlorite contain, which makes it difficult for users to decide on the dosage, particularly when in pellet form (CDC, 2006). Too small a dose may result in ineffectively treated water; while too high a dosage results in unpleasant tasting water (CDC, 2006). Its limitations include those of other hypochlorite-based treatment methods as noted above.

Sodium Dichloroisocyanurate (NaDCC)

Aquatabs (NaDCC) are effervescent chlorine tablets manufactured by Medentech Ltd under the brand name, Aquatab. Each tablet is made up of three major constituents: sodium dichloroisocyanurate, adipic acid, and sodium carbonate (Swanton, 2008). A pack of 20 tablets costs 60 KES ($0.71 at 84 KES: $1; Swanton, 2008). A dosage of 2 mg/l is recommended for clear water and 4–6 mg/l for faecally contaminated or unclear water (Swanton, 2008). The instructions for use indicate that the recommended dosage of Aquatab should be dropped into the water to be treated, allowed to dissolve and a 30 minute waiting period observed before consuming the treated water (Swanton, 2008).

Its mechanism of action is similar to sodium hypochlorite (NaOCl) as it uses hypochlorous acid as the major disinfecting agent. However, it differs in that, unlike NaOCl, NaDCC releases only about half of the chlorine as Free Available Chlorine (FAC); the balance is progressively released as the FAC is used up, thus NaDCC acts as a reservoir which is readily accessible (Clasen and Edmonson, 2005).

According to Clasen and Edmonson (2005), NaDCC's advantages over NaOCl include its effectiveness over a wider pH range than NaOCl, because the alkalinity of NaOCl when in solution favours the production of the weaker hypochlorite ion while the NaDCC‘s acidity in solution favours the production of hypochlorous acid, the stronger disinfectant. Other advantages include NaDCC's ease of handling due to its tablet form, unlike the liquid NaOCl; its higher stability indicated by a shelf life of five years in comparison to NaOCl's six months even when properly stored in an opaque bottle (Clasen and Edmonson, 2005).

PUR

This flocculant-disinfectant (Procter and Gamble Co, Mason, OH, USA) is a combination of ferric sulphate and calcium hypochlorite granules which treats water with a combination of coagulation, flocculation and disinfection (Crump *et al.*, 2004; Lantagne *et al.*, 2006; WBCSD, 2006). It is marketed as PUR or Watermaker in Kenya. A sachet produced by Procter & Gamble is sold at a subsidised cost of KES7.

Users are instructed to add one PUR sachet to 10 liters of water in an open bucket, stir for five minutes, allow the solids to settle and then strain the resultant floc through a cloth filter into a second container (WBCSD, 2006). Users should then wait for 20 minutes to allow the hypochlorite to inactivate microorganisms (Lantagne *et al.*, 2006).

The advantages of PUR include its effectiveness on a wide range of pathogens in highly turbid waters, including oocysts of *Cryptosporidium parvum* and *Giardia lamblia*, residual protection and possible reduction of the carcinogens associated with chlorination of turbid water (Crump *et al.*, 2004; Lantagne *et al.*, 2006). Its disadvantages are: the introduction of an extra step to disinfection; the requirements of more equipment in comparison to other hypochlorite-based methods, as well as the need to carefully dispose of the floc formed after treatment which increases the process time and potential for non-compliance (Sobsey *et al*., 2008).

(b) Physical removal processes

Ceramic filters

Ceramic filters may be candle or pot filters (Mahlangu *et al.,* 2012). Ceramic candle filters are made from diatomite or clays which have been mixed with combustible material such as rice husks, moulded into a candle shape and fired in an oven, to develop the pores through which water can be filtered (Brown and Sobsey, 2010; Mahlangu *et al.*, 2012).

The ceramic pot filters produced by Potters for Peace (PFP) are the most widely promoted version and non-governmental organisations promote variations of the PFP design (Clasen et *al.,* 2004; Lantagne *et al.,* 2006). A PFP ceramic filter unit is made up of a porous ceramic element which is hollow and fitted into a top container of 8.2–10 l capacity, which in turn rests in the filter's 20–30 l safe storage container, and a cover for the ceramic element (Lantagne *et al.*, 2006 Clasen *et al.,* 2004). Raw water is poured through the top and the treated water collected through a tap fitted to the lower receptacle (Swanton, 2008). In Kenya, an entrepreneur model is used in which local small-scale business people receive training and initial equipment to begin manufacture (Lantagne *et al.,* 2006). One such example is Chujio industries who manufacture Chujio filters, which are shaped like a flower pot and treated with colloidal silver as a bacteriostatic agent, to enhance the filter's gravity-aided filtration (Swanton, 2008; Solidarites International, 2011). The flow rate of the Chujio filter allows a production of 2.5 l of water per hour (Solidarites International, 2011).

A ceramic filter uses porous, fired clay media to remove microbes from drinking water by particle exclusion. Since this exclusion is based on the pore sizes, the pore size is an indicator of quality; the smaller the size, the better the quality. Good quality filters have micron or sub-micron ratings (Clasen *et al.,* 2004; Lantagne *et al.,* 2006; Sobsey *et al*., 2008) and can be as small as 0.2 µm (Brown and Sobsey, 2010).

The advantages of ceramic filters are their ability to produce adequate quantities of safe water at the point-of-use; effectiveness in the removal of parasites and bacteria; appropriateness in emergency situations as well as in households that have no safe water supply; their durability, ease of use and low maintenance requirements (du Preez *et al.,* 2008; Sobsey *et al.,* 2008). Other advantages include their portability, the absence of change in the taste of treated water, non-requirement of an external energy source, and the potential for generating income for locals when produced locally (du Preez *et al.,* 2008; Sobsey *et al.,* 2008; Brown and Sobsey, 2010).

Their limitations are the fragility of the filter media; the lack of certainty about their effect on viruses; the absence of a residual effect and the high cost of purchase (Lantagne *et al.,* 2006; Sobsey *et al.,* 2008). Ceramic filters cost $60 dollars with about $6 for each candle, compared to chlorination which is estimated to cost between $2.20 and $11 dollars for capital and operating costs (du Preez *et al.,* 2008). The local manufacture of ceramic filters may reduce costs of ceramic filters, a PFP ceramic filter may cost between $7.50 and $30 (CDC, 2012a). Though Lantagne *et al.* (2006) and Brown and Sobsey (2010) view the ability to produce them locally as an advantage, the costs are still high in Kenya where the cost of ceramic filters varies from one organization to the other. For example Chujio sell a filter for 1 700 KES ($20 at 84 KES: $1), while the same filter is sold by SWAP, the NGO whose study sites form the sampling frame for this project at a subsidised cost of 1 000 KES ($11.90 at 84 KES: $1).

Biosand Filter

A Biosand filter (BSF) is a home-scale version of the slow sand filter which has been used in water treatment plants for more than 150 years (Duke *et al*., 2006). An example is the Manz Biosand intermittent slow sand filter which was adapted by Dr David Manz from using a continuous flow principle, to one which works by intermittent flow (Duke *et al*., 2006). The Manz Biosand filter is being used in 20 developing countries such as Honduras, Mexico, the Dominican Republic, India, Pakistan, Nepal and Uganda (Duke *et al*., 2006). A BSF is a 0.9 m high and 0.3 m wide concrete container filled with sand. A plate with holes is placed on top to prevent the bioactive layer from being disturbed when water is added to the filter. Source water is poured into the BSF, it passes through the filter media which consists of concurrent layers of fine, coarse sand and gravel and the finished water is collected through an outlet (Duke *et al.*, 2006). The flow rate is 30–40 l/h with a maximum of 60 l/h (Duke *et al.*, 2006).

The filter uses a combination of processes such as mechanical exclusion of the particles based on the sizes of the spaces between the sand granules, adsorption of suspended materials on sand granule surfaces, and microbiological activity in a layer of bioactive sand known as Schmutzdecke, which develops as a result of aerobic respiration facilitating the growth of microorganisms in the top layer of sand (Duke *et al.*, 2006, Mahlangu *et al.*, 2012).

The Biosand filter has similar advantages to the ceramic filters: ease of use, ability to produce sufficient quantities of water at the point-of-use, efficacy on bacteria and protozoa, one-time installment and low maintenance requirements (Lantagne *et al.*, 2006; Sobsey *et al.*, 2008). It has an additional advantage over ceramic filters by not being prone to filter element breakage. Its limitations include its low proven efficacy for viruses, its poor portability because of its size, lack of residual effect and its high initial costs (Lantagne *et al.*, 2006; Sobsey *et al.*, 2008). The Manz Biosand filter costs about $25 (4 000 KES)

(c) Heat disinfection

Boiling

This involves boiling water to inactivate viral, parasitic and bacterial pathogens. Boiling has economic and environmental constraints, it is inconvenient and some users dislike the taste of boiled water. Boiling has no residual value against recontamination (Mintz *et al.*, 2001).

Solar disinfection

The term refers to those technologies that disinfect water by solar irradiation (WHO, 2008). In some solar disinfection technologies, the inactivation of microbes might rely on the effect of heat from solar energy on water placed in the sun in opaque containers. Others such as the SODIS, which will be reviewed in this study, uses the penetration of UVA radiation from the sun on water in clear plastic or Polyethylene Terephthalate (PET) containers (Graf *et al.*, 2008; WHO, 2008). The technique was popularized by Acra *et al.* (1990) who noted that the most effective spectral band for SODIS is the ultraviolet optimum of 357 nm. SODIS was introduced in Kenya on a large scale in March 2004 through the Kenya Water for Health Organization (KWAHO), who implemented a SODIS project in Kibera, the largest urban slum in Africa with about one million inhabitants (Lantagne *et al.,* 2006).

It works using the effect of light and heat on bacteria (Schmid *et. al.,* 2008). Berney *et al.* (2006) found that *E. coli* cells exposed to UVA radiation corresponding to 530 W m^{-2} were not able to recover from the damage to their cells. In addition to the direct inactivation from the UVA radiation (Wegelin *et al*., 2001; Kehoe *et al*., 2004), there is also a synergistic effect of heat and the light waves which occurs at temperatures above 45 ^{0}C–50 ^{0}C (Wegelin *et al*., 1994, Kehoe *et al.*, 2004),

Since Accra's pioneering work in the nineties, several studies have been carried out by researchers in different parts of the world to investigate the effect of factors such as the minimum number of hours of exposure, container characteristics (type, shape, size and color of container), turbidity, water temperature, water volume, bactericidal effects on specific pathogens and possibilities of regrowth after treatment (Enabor, 1998; Wegelin *et al*., 2001; Kehoe *et al*., 2004; Berney *et al.,* 2006 Graf *et al.,* 2008). As a result of some of these studies, guidelines were developed for optimal SODIS action. These recommend exposing water to sunlight for at least five to eight hours (Wegelin *et al*., 2001; Kehoe *et al*., 2004; Graf *et al.,* 2008) on roof tops under clear skies, to a dose of 555 W m^{-2}. This is considered as sufficient irradiation and time at water temperatures between 30 ^{0}C–40 ^{0}C for a 3 log reduction of *E. coli* (Wegelin *et al*., 1994). The same dose will inactivate bacteriophage f2 and rotavirus to the same extent at a water temperature of 30 ^{0}C (Wegelin *et.al*., 1994). In addition to sufficient exposure to sunlight, the guidelines recommend using transparent polyethylene terephthalate (PET) plastic bottles as the container type and material ideal for SODIS (Wegelin *et al.,* 2001; Graf *et al.*, 2008). Bottles are preferred because, although transparent plastic bags have a greater surface area, they leave a plastic taste in water and are difficult to handle (SODIS, 1998). Though transparent glass bottles are less reactive, they are heavy, more expensive than PET and are prone to breakage (Wegelin *et al*., 2001). Necessary precautions are that SODIS should not be used to treat water with turbidity above 30 NTU and small quantities of well aerated water should be treated at a time to maximise the bactericidal effects from the reaction of sunlight with oxygen (Wegelin *et al*., 1994; Kehoe *et al*., 2004).

In addition to providing information to optimize the efficacy of SODIS, the possible side effects of the use of PET bottles were investigated by Schmid *et al.* (2008). There was a concern that the exposure of water in PET bottles to sunlight might result in health risks from the possible of the plasticizers di (2-ethylhexyl) adipate (DEHA) and di(2-ethylhexyl) phthalate (DEHP) introduction into the water. Schmid *et al.* (2008) found that the concentrations of DEHA and DEHP (0.046 and 0.71 µg/l, respectively) in disinfected water were in the same range as that found in commercially bottled water, based on recommended guidelines, and were of no health risks to consumers.

The advantages of SODIS include its proven efficacy against bacteria, viruses and protozoa (Lantagne *et al.,* 2006), its ease of use and its comparatively low capital and maintenance costs (Graf *et. al.,* 2008; Schmid *et al*., 2008). For instance, a 1.5 l bottle costs 15 KES ($0.18 at 84 KES: $1). Other advantages of SODIS include its limited dependence on a supply chain apart from the need for PET bottles (Graf *et al.*, 2008, Schmid *et al*., 2008); the unchanged taste of water after treatment with SODIS (SODIS 1998; Lantagne *et al.,* 2006; Schmid *et al.*, 2008); its ability to protect the treated water from recontamination by virtue of the water being disinfected in a bottle that also serves as the storage container (Lantagne *et al.*, 2006; Schmid *et al.*, 2008).

The disadvantages of SODIS include its reduced efficacy in highly turbid waters (Lantagne *et al*., 2006; Schmid *et. al.,* 2008); inefficacy against *Ascaris* larvae and *Cryptosporidium* Heaselgrave and Kilvington (2011); the relatively small quantities that can be disinfected (Wegelin *et al*., 2001); the method's dependence on a continuous availability of sunlight which varies with geographical location and time (Wegelin *et al.,* 1994; Schmid *et al*., 2008), and the relatively long time for disinfection; between six hours and two days (Schmid *et al*., 2008).

1.13 Risk reduction of water-borne diseases with household water treatment technologies

Household water treatment technologies are necessary either because of inadequate access to an improved water source, or due to recontamination of unreliable improved sources (WHO, 2011). However, because of the constraints of household level water quality monitoring, the classification of a source as improved is not based on the quality of the water and does not mean that the improved source meets recommended drinking water guidelines (WHO, 2011). In recognition of the fact that the poor quality of water observed during monitoring may be symptomatic of problems outside the immediate drinking water system, The WHO guidelines for drinking water quality management recommends a drinking water quality framework of integrated preventive measures for drinking water quality management (WHO, 2008: Figure 1.3).

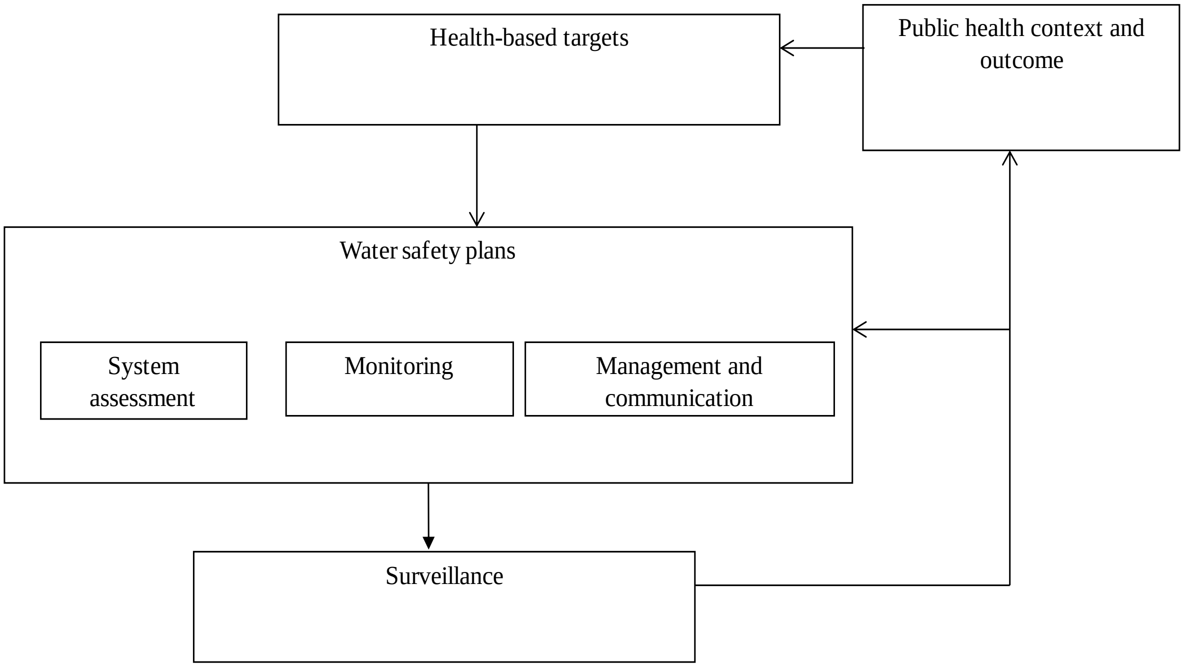


Figure 1.3 The WHO framework for safe drinking water (WHO, 2008).

The drinking water quality framework

The drinking water quality framework is an attempt to encourage water services authorities to move away from managing drinking water quality with a reactive approach, based on the quality of the treated water to an approach based on risk-prevention (WHO, 2008). The framework is based on the principles of risk analysis and risk management and comprises five major components which are: health-based targets; integrated system assessment to determine whether the water supply system is able to deliver potable water from catchment to the point-of-use; operational monitoring of the control processes that ensure safe water supply; management plans; documentation and communication with consumer, and independent monitoring and surveillance (Howard *et al.,* 2006; WHO, 2008). The risk management aspects of the framework refer to the documentation, implementation and monitoring of the control processes; the development and implementation of management plans and communication with consumers. The risk assessment aspects are related to health-based target setting and water safety planning. They are however not separate but iterative processes (Medema and Ashbolt, 2006).

Water safety plans are the planning tools which enable the water services authorities to put the drinking water framework into operation and plan to meet the health-based targets incrementally (WHO, 2008). The plans incorporate three of the components of the drinking water quality framework: system assessment and design, operational monitoring and the development of management plans (Davision *et al.,* 2005). Management plans include documentation and communication with the consumer (Davision *et al.,* 2005). Water safety plans use country-specific health-based targets, which are usually adapted from the global WHO drinking water quality norms and standards to manage drinking water quality (Davidson *et al.,* 2005; WHO, 2008*).* The health-based targets, incorporated in the water safety plans, serve as benchmarks against which water service authorities can monitor the efficiency of their processes through internal self-assessments and externally conducted independent evaluations (Davison *et al*., 2005).

Quantitative Microbial Risk Assessment

A first step in setting health-based targets in many countries would be the development of a target which seeks to reduce the overall burden of disease by providing environmental health interventions such as water treatment at the household or more centralized level (Havelaar and Melse, 2003). The gains achieved by meeting the targets can be easily quantified by using epidemiological approaches in situations where there is a high prevalence of enteric disease (WHO, 2008). However in some situations where the enteric disease burden is low, the use of such approaches may not adequately measure progress towards health-based targets, as they are not able to show the link between the improvement in water quality and the reduction of disease (Haverlaar and Melse, 2003). In this and other situations where it is difficult to measure the incidence and prevalence of disease by normal public health surveillance, quantitative microbial risk assessments can be carried out as an alternative strategy (Harvelaar and Melse, 2003; Medema and Ashbolt, 2006). The major difference between quantitative risk assessment, such as quantitative microbial risk assessment (QMRA) and epidemiological approaches, is that the former attempts to calculate the risk from a pathogen using inferences from the pathogen's infectivity and occurrence, while the latter seeks to measure the disease levels in the population of interest (Hunter *et al.*, 2003). Though QMRA has been used more commonly in developed countries to evaluate the burden of disease contacted through the drinking water exposure route, it is also valuable in developing countries where it is difficult to quantify the proportion of enteric disease linked to drinking water, because in these countries, there are other routes of exposure to enteric diseases, such as poor sanitation and inadequate hygiene (Ashbolt, 2004a; Howard *et al.*, 2006).

Carrying out a risk assessment in the drinking water sector

In the food industry, risk assessment typically consists of consists of four steps: hazard identification, exposure assessment, hazard characterization and risk characterization (Lammerding and Fazil, 2000). Within the drinking water quality sector, the main steps for carrying out a quantitative microbial risk assessment to determine the burden of disease from specific pathogens are exposure assessment, dose-response analysis and risk characterization (Howard *et al.*, 2006). The major difference in the use of risk assessment between the two sectors is the hazard identification, because, unlike the food sector, the pathogenicity of the microbe of interest would usually have been documented and the cause-effect relationship established in the drinking water sector (Lammerding and Fazil, 2000, Hunter *et al*., 2003).

Nevertheless, hazard identification is relevant to water safety planning because it is a key objective of the system assessment stage of the drinking water quality framework and it is integral to drinking water quality management (Davison *et al.*, 2005; WHO, 2008).

Hazard identification

The term "hazard" refers to any biological, chemical, physical or radiological agent that can potentially cause an adverse effect (Davison *et al.,* 2005; Lammerding and Fazil, 2000). A QMRA assesses the risks from biological hazards which may be pathogenic or non-pathogenic; examples of pathogenic hazards are viruses, bacteria, helminthes and protozoa, while non-pathogenic hazards may include *Cyclops* and *Asellus* (Davidson *et al*., 2005).

Within the context of the drinking water quality management framework, hazard identification means water safety planners must consider all potential hazards that may impact on the water supply from catchment to the point-of-consumption, their route of entry into the drinking water supply system, as well as the as the identification of possible control measures (Davison *et al*., 2005). Such systematic identification must take place within the broader context of other environmental and public health factors such as sanitation, the reduction of pathogens in water and an improvement in water resources management (WHO, 2008). During the hazard identification stage it is also important to determine the susceptible populations, in terms of gender and age, and the severity of the outcome in terms of morbidity, mortality and asymptomatic infections (Hunter *et al*., 2003).

Exposure assessment

Exposure assessment is the quantitative assessment of the likelihood of an individual or population being exposed to a hazard (Lammerding and Fazil, 2000; Medema and Ashbolt, 2006). The process involves the determining the number of the particular microbes of interest or their surrogates within the distribution network prior to treatment in raw water and after treatment (Hunter *et al.,* 2003; Medema and Ashbolt, 2006*).* The quantitative information on the occurrence of the specific pathogen of interest and quantity of water consumed by the population of interest is translated into a risk estimate of the potential exposure using known dose-response models (Lammerding and Fazil, 2000; Hunter *et al.,* 2003; Medema and Ashbolt, 2006).

Dose-response models

Dose-response data exist which can be used to develop predictive models for estimating the dose-response relationships for microbes of interest (Hunter *et al.*, 2003). However it is important to recognize that these dose-response models have been derived from studies on healthy individuals, and therefore the effect on immune-compromised adults and children will be more severe (Hunter *et al.,* 2003). For example, HIV-positive persons may die from cryptosporidiosis while the response of healthy individuals may be limited to episodes of diarrhoea which lasts for many days.

Initially, in the fifties, dose-response curves were based on a single-hit model in which a simple exponential relationship modelled an assumption that only one hazard particle is needed for an infection (Ashbolt, 2004b). In the sixties, a beta-poisson model was developed which incorporated the heterogeneity in the occurrence of pathogens in its assumptions; this is the model that is commonly used for risk assessments and has been used for the assessment of health outcomes in the standardisation of the drinking water quality guidelines (Ashbolt, 2004b).

Some adaptations have had to be made to QMRA modelling to enable its use in developing countries. QMRA modelling traditionally incorporated Monte Carlo simulations to quantify and include uncertainties within frequency distributions to arrive at a distribution of risk which represents the range of risk within various scenarios (Lammerding and Fazil, 2000; Howard *et al.,* 2006). However, some of the software needed for the simulations is both proprietary and expensive (Howard *et al.*, 2006). WHO therefore approves a simplified method using a single point estimate, in which single points are used as inputs by determining the average or worst-case scenarios (Lammerding and Fazil, 2000; Howard *et al.*, 2006). For example, the quantity of pathogens an individual is exposed to is calculated from the average quantity of food consumed and the average counts of pathogens the food is likely to contain (Lammerding and Fazil, 2000).

Another adaptation, which is not limited to developing countries, is the use of surrogates. This adaptation is necessary because dose-response data for estimating the effects of specific pathogens do not exist for every micro-organism, but the dose or number of micro-organisms ingested can be estimated directly or indirectly with the use of surrogates (Hunter *et al.,* 2003; Howard *et al*., 2006; van Lieverloo *et al.,* 2007*).*The use of surrogates, or reference pathogens is also informed by the impracticability in terms of financial, human and time-related resources of completing a QMRA for each pathogen of interest (Howard *et al.*, 2006), as well as the need to increase the applicability of QMRA modelling to the developing world, where data is often not available for every pathogen of interest (Haas *et al.*, 1993; van Lieverloo *et al.,* 2007).

The use of reference pathogens has certain drawbacks. For example, the use of such indicator organisms will necessitate making assumptions about the relationship between the pathogen of interest and the indicator organisms, as well as similarities of effect between indicator organisms and humans, and pathogens of interest and humans (Howard *et al.*, 2006). The use of reference pathogens also adds an element of uncertainty to the uncertainty which already exists in risk assessment measurements as a result of the highly variable occurrence of pathogens in water (Howard *et al.,* 2006). In spite of these uncertainties and because QMRA is a valuable tool for drinking water quality management, the adapted version and the use of surrogates is acceptable within the developing world context (Howard *et al*., 2006).

WHO recommends the use of reference pathogens, whose presence can be used to infer the presence of other pathogens, examples of which include the coliforms, total heterotrophic bacteria, F-RNA coliphages and *E. coli* (Ashbolt *et al*., 2001; Hunter *et al.,* 2003*)* (Table 1.7).

Table 1.7 Definitions for indicator and index microorganisms of public health concern (Ashbolt *et. al.*, 2001).

Group	**Definition**
Process indicator	A group of organisms that demonstrates the efficacy of a process, such as total heterotrophic bacteria or total coliforms for chlorine disinfection.
Faecal indicator	A group of organisms that indicates the presence of faecal contamination, such as the bacterial groups thermotolerant coliforms or *E. coli*. Hence, they only infer that pathogens may be present.
Index and model organisms	A group/or species indicative of pathogen presence and behaviour respectively, such as *E. coli* as an index for *Salmonella* and F-RNA coliphages as models of human enteric viruses.

2. GENERAL METHODS

This chapter presents the study design, study area and the methods used for the study village selection for sampling, data collection and water quality analysis.

2.1 Study design

This study assessed the effectiveness of selected household water treatment (HWT) technologies. Effectiveness refers to the measurement of the efficacy of an intervention as well as its application and acceptance within a real-world context by using human-related factors as well as empirical data such as water quality data (McLaughlin *et al*., 2009). The operational framework is shown in Figure 2.1.

In theory, the best design for water and sanitation evaluations would be randomised experiments in which controls are used and researchers do not control the assignment of study subjects to treatment groups. The confounding biases that may arise from non-randomization are thus addressed and this allows the valid measurement of outcomes and treatment, not only at baseline, but throughout the study (Gomm, 2008; Arnold *et al.*, 2009). Examples of such randomized designs are longitudinal cohort studies which require a scientifically structured design and a follow-up of study participants for a number of years. However, the experimental, randomised design is seldom feasible because few funders are willing to provide grants for prolonged water and sanitation studies (Arnold *et al*., 2009). Furthermore, using a randomised design to determine the effectiveness of an intervention suggests that the researcher is creating rigidly structured experimental scenarios, which are unrealistic and not replicable in real-world situations (Gomm, 2008).

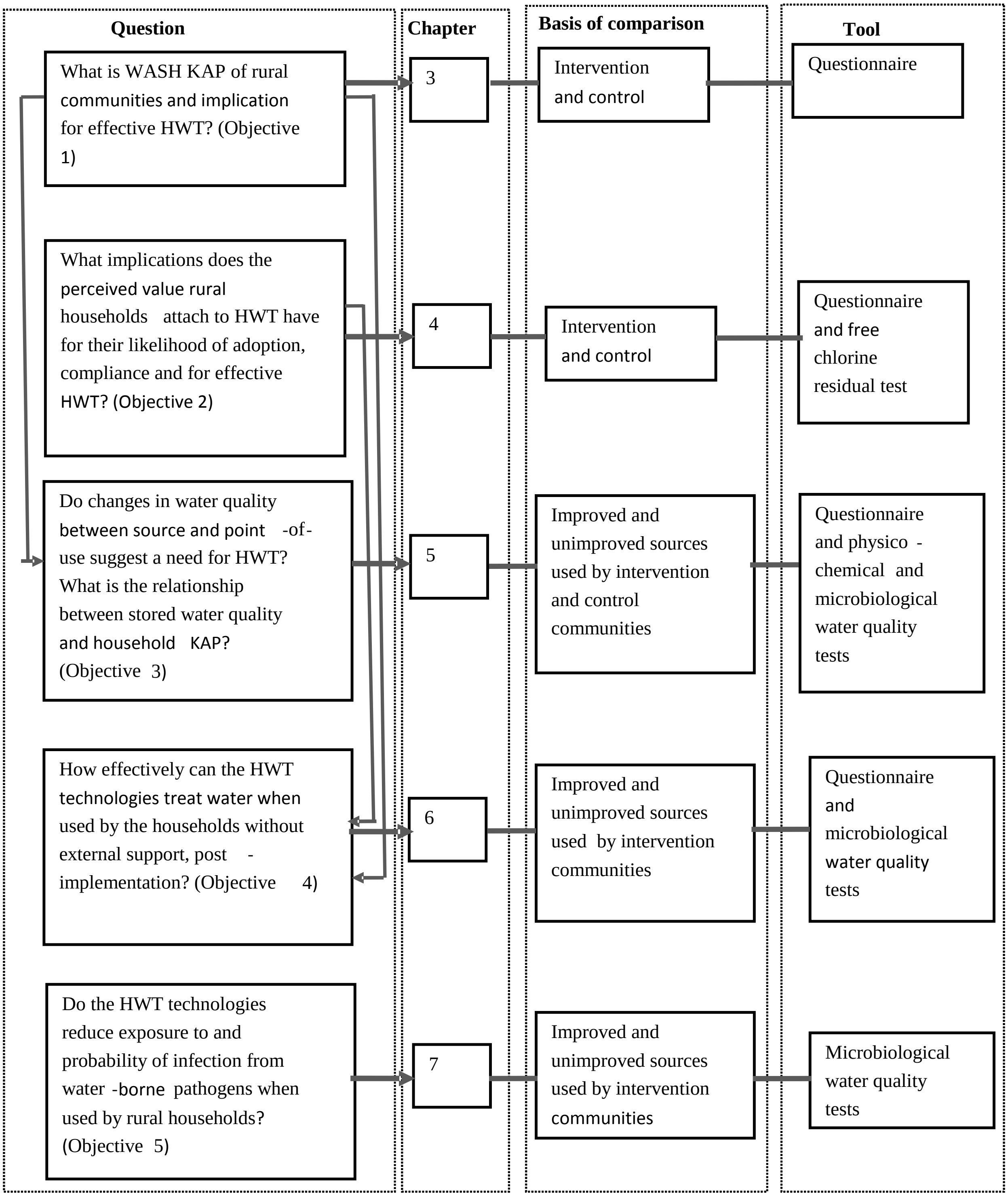


Figure 2.1 Linkage between study aim, research questions, objectives, data sets and data collection tools.

At the other end of the scale of design possibilities are non-experimental designs or observational studies. The validity weaknesses of impact studies which use the observational study design alone include the absence of adequate controls, health indicator recall, self-reporting biases, and poorly addressed confounding variables (Blum and Feachem, 1983; Arnold *et al*., 2009). However, Mclaughlin *et al*. (2009) noted that intervention studies which compare HWT treatment households with control households that do not use HWT were subject to bias and the higher microbial reductions which are reported might be as a result of follow-up support given to HWT treatment households, which is absent in non-HWT households. They therefore argued that an observational design is more appropriate for evaluating the effectiveness of HWT technologies.

Given the above, a quasi-experimental design based on pre-existing household water treatment interventions, and one which makes use of controls as proposed by Arnold *et al*. (2009), was used to address the study objectives that assessed the 'setting' or contextual and human-related factors. This was done in order to minimise the types of bias that would occur without controls. An observational study design was used to address the objectives for assessing the effectiveness of HWT as used by households in order to minimise effect biases, which might occur because of the external support provided to the HWT-using households during the promotion stage. Variables such as category of source type were then used as the basis of comparison for the empirical data such as water quality and probability of risk obtained in the course of addressing these objectives.

Shadish *et al.* (2002) describe a quasi-experimental design as one that is similar to the experimental design in all aspects except for the randomisation of the study subjects. This study satisfied the conditions that Shadish *et al.* (2002) specify for such a study to infer a cause validly. First, cause must precede effect: in this study, the water treatment precedes the effect of microbial quality improvement in drinking water. Second, the cause or the intervention being studied varies with effect: in this study, there was a difference in quality of water before treatment and after treatment. Third, the effect observed (the improvement in water quality) should not be attributable to other factors or confounders: in this study, confounders such as education were adjusted for through the design of the study, which used matched intervention and control villages.

The study used pre-existing water and sanitation interventions which Arnold *et al*. (2009) defines as those that were designed and implemented prior to a structured scientific study. The use of pre-existing interventions in this study conforms to Blum and Feachem's (1983) view that it is preferable to focus on 'opportunistic' studies using existing water and sanitation programs, rather than designing interventions specifically for the purpose of research, because, though they are scientifically structured, they may not be representative of the usual intervention programs, or be replicable.

Another advantage of using studies in which interventions have been previously carried out is that this approach is consistent with the principles of randomisation, especially if the first intervention village is randomly chosen within the geographical area specified by the government or other implementing agencies (Blum and Feachem, 1983).

The use of pre-existing interventions in this study has the following advantages:

a) Reduction of self-reporting bias: The problem with impact studies carried out during an intervention where data is collected under intense monitoring is that the behaviour of study participants may be altered, which raises questions about the comparability of the results with real-world situations. Studies that use pre-existing interventions are implemented without such rigorous monitoring by research staff since they are reporting the findings after interventions (Arnold *et al*., 2009). This study was a field-based experiment in which the researcher was able to introduce some control into an otherwise naturally occurring situation. In this way the researcher made the least possible impact while still being able to address the criticism about the artificiality of rigorously controlled experimental studies (Gomm, 2008).

b) Cost and time savings: Important information was obtained from the implementing organization, such as the selection criteria for household water treatment users, duration and location of the former intervention activities, and access to comprehensive household lists used by the earlier interventions.

The study met all but one of the criteria which pre-existing interventions should ideally satisfy to qualify for use in a quasi-experimental study (Table 2.1; Arnold *et al*., 2009), and that was the availability of baseline data from the implementing organisations, KWAHO and SWAP.

Arnold *et al*. (2009) recognized the unavailability of data as one of the possible methodological problems that might be encountered in an attempt to use pre-existing interventions for evaluations. In this study, this problem was addressed by collecting data on the socio-economic characteristics of the intervention and control communities. This was carried out as part of the KAP survey conducted at the onset of this study. Twenty socio-economic variables which might affect the effectiveness of HWT interventions were used to compare the intervention and control communities (Table 2.2). The following inferences could be made if there was no significant difference between the two types of study communities in most of the variables:

a) Both the intervention and study communities were well matched, and
b) that the structured intervention had not changed the socio-economic characteristics of the communities and
c) any significant differences between them in terms of levels of HWT related human behaviour (adoption and compliance) could be attributed to the method of introducing the HWT intervention program and
d) the findings of HWT effectiveness obtained from assessing the intervention communities could be generalised to other rural communities within Kenya which share similar socio-economic characteristics.

The other activities which were carried out as recommended when using pre-existing interventions are shown in Table 2.3.

Table 2.1 Criteria for using pre-existing interventions (Arnold *et al*., 2009).

Condition	**Main rationale**
1. A partnership with the implementing organization	The implementing organization is the key provider of information about the intervention components, how the intervention beneficiaries were selected, and the timeline and location of activities
2. Sufficient intervention scale	Each community is a single unit of analysis and adequate numbers are needed for valid statistical analyses
3. Availability of control communities	Control communities are necessary to provide a counter-factual comparison group
4. Independence of communities	Theoretical and statistical constructs require that each community is independent with respect to the intervention and the outcome of interest.
5. Uniformity of the intervention across communities	A uniform intervention is necessary to define and estimate a common treatment effect across communities.
6. Availability of baseline (pre-intervention) data	Baseline data allow investigators to establish baseline comparability between intervention and control communities. Baseline data also provides information for informative sampling

Table 2.2 Variables used to assess similarity between intervention and control communities.

	Variable
1.	Female:male KAP respondent ratio
2.	Mean stay of household in community in years
3.	Average age of respondent
4.	Marital status
5.	Unemployment of KAP respondent
6.	Employment of KAP respondent
7.	Unemployment of household head
8.	Employment of household head
9.	Adopter profile of household head (credit group)
10.	Adopter profile of household head (female/male group)
11.	Adopter profile of household head (religious)
12.	Adopter profile of household head (burial committee)
13.	Mean age of youngest child in house
14.	Households poverty profile
15.	Dominant material used for floor
16.	Dominant material used for roof
17.	How household heard of current drinking water treatment method
18.	Educational level of respondent of adoption survey
19.	Households with children aged below 5 years old
20.	Mean household size

KAP; Knowledge, Attitudes and Practices; Adopter profile; Quantitative indication of adoption of an intervention using membership of community groups as proxy indicator.

Table 2.3 The key activities in a quasi-experimental design for evaluating a non-randomised pre-existing intervention adapted from Arnold *et al*. (2009).

Step	**Intervention activities**	**Recommended evaluation activities (Arnold, 2009))**	**Actual activities carried out in this HWT study**
1		Pre-intervention secondary data such as socioeconomic indices, collected on a large set of communities (by implementing organization, national census, or other source)	Pre-intervention data available in communities in which SWAP* was the implementing organization but not available in KWAHO# implemented communities
2	Intervention communities selected		
3	Intervention begins		
4	Intervention ends		Intervention had ended at least a year before the HWT study to ensure that the study was assessing real-world situations where communities were no longer receiving any external support
5		Evaluation study is conceived. Investigators contact the implementing organization to establish a relationship and collect key information about the intervention. Investigators obtain secondary data (collected in step 1).	Study was conceived. Investigators contacted the implementing organization, established a relationship and collected key information about the intervention. Investigators obtained the secondary data that was available
6		Intervention and matched control communities selected based on pre-intervention secondary data	Intervention and matched control communities were selected based on pre-intervention secondary data and field experience of implementing organization staff
7		Post-intervention data collection in selected communities	Post-intervention data was collected in selected communities

*SWAP: Safe Water and Poverty Project; #KWAHO; Kenyan Water and Health Organisation;

The study planned to assess the real-world effectiveness of a range of HWT methods which had been assessed by other studies for microbiological efficacy and their effect on reducing diarrhoeal disease (Sobsey *et*. *al*., 2008). They include:

a) Liquid chlorine (Sodium hypochlorite): Waterguard brand, manufactured by Jet chemicals, Kenya)

b) Sodium Dichloroisocyanurate (NaDCC): effervescent chlorine tablets (branded Aquatab, manufactured by Medentech, Ireland)

c) Combined chlorine and flocculants: PUR brand, marketed by Procter and Gamble, Cincinnati, OH)

d) Ceramic filter in which porous ceramic (fired clay) media is used to filter microbes from drinking water (manufactured locally by Chujio Ltd.)

e) Boiling, to inactivate pathogens in drinking water

f) The Biosand Filter (BSF): a modification of the large-scale, slow sand filter, for use at the household level

g) SODIS: Solar disinfection, using transparent polyethylene terephthalate (PET or PETE) bottles.

Since SODIS and Biosand filters were not used by any of the intervention or control households, technologies a–-d were the methods assessed in every stage of the study, i.e. the adoption and compliance survey, the HWT effectiveness assessment and HWT risk assessment. SODIS was however, assessed during the adoption and compliance HWT survey as some households within the sampling frame had heard of the method.

2.2 Description of the study area

Kenya is an independent republic which lies on the Indian Ocean coast and forms part of the East African Region (Figure 2.2). It has a population of 38 610 097 and an area of 582 650 km^2 (KNBS, 2009b). The capital city is Nairobi, and other major towns are Nakuru, Kisumu and the Port of Mombasa. The country is split into eight provinces, with 2 461 cities and towns (UNESCO 2006). Its administrative divisions are province, division, location, sub-location and village.

Kenya is a water-scarce country and mean annual rainfall in the country is approximately 630 mm, with huge variability between regions, for example 200 mm in the north to 1 800 mm in the western region (UNESCO, 2006). The per capita available water is an estimated 650 m^3/year

(UNESCO, 2006). Kenya has a total improved drinking water and sanitation coverage of 59% and 27%, respectively (WHO/UNICEF, 2010).

The study was conducted in the Western and Nyanza provinces of Kenya. Nyanza province is located between latitudes 0.5^{o}N–0.5^{o}S and longitudes 34^{o}E–34.667^{o}E (NEMA, 2007a). The province is divided into 21 administrative districts and has a total area of 12 612.9 km^{2}, a population of 5 442 711 and a population density of 432 persons/km^{2} (KNBS, 2009a). The province has various challenges which include perennial floods, soil erosion, poor waste management and poor access to improved water and sanitation (NEMA, 2007a).

Western province is located within latitudes 0^{o}–0.5^{o}N and longitudes 34.483^{o}E–34.583^{o}E (NEMA, 2007b). The province has 20 districts, a population of 4 334 282 within a total area of 8 309.3 km^{2} and population density of 522 persons/ km^{2}, (KNBS, 2009b). Over 70% of the population lives in rural areas with an estimated poverty level of 68% (NEMA, 2007b). The Western and Nyanza provinces share environmental health challenges such as low access to water and sanitation and the common practice of open defecation. Loose soils, floods and a high water table combine to increase the challenge of improving sanitation.

The study was conducted in four districts of the Nyanza and Western Provinces, namely Kisumu East, Budalangi, Nyatike and Nyando districts (Figure 2.3). Kisumu East district is one of the 35 districts in Nyanza province, spanning an area of 557.7 km^{2} (Government of Kenya, 2009). Kisumu East lies within latitudes 0.333^{0}S–0.833^{0}S and longitudes 34.167^{o}E–34.75^{0}E. It has a total of 20 locations and 55 sub-locations falling within two divisions, namely Winam and Kadibo divisions (Government of Kenya, 2009). The district has a total population of 378 872 persons with a 1:1 male:female ratio (KNBS, 2009b). According to the Government of Kenya, (2009), the main challenges in the district include inadequate funding, flooding in the Kadibo division, periodical droughts and HIV/AIDS. The environmental challenges in the district are the discharge of raw wastes into Lake Victoria and the resultant excessive growth of water hyacinth in Lake Victoria and other rivers (Government of Kenya, 2009).

According to the Government of Kenya (2009), the socio-economic indices of the district include an absolute poverty level of 49% and a gross school enrolment rate of 51% for males and

49% for females. An estimated 35.49% of households have access to piped water, while 52.96% have access to improved water sources. The under-five mortality rate at 220/1000 is high while life expectancy is poor at 50 years for females and 47 years for males (KNBS, 2009b).

Preliminary discussions with the NGOs that carried out the HWT interventions in the intervention villages revealed that the intervention and control villages in the four districts shared some characteristics. The villages are predominantly rural and lack educational and health facilities. They use rivers, seasonal ponds and rainwater as their main drinking water sources and have poor sanitation coverage and awareness.

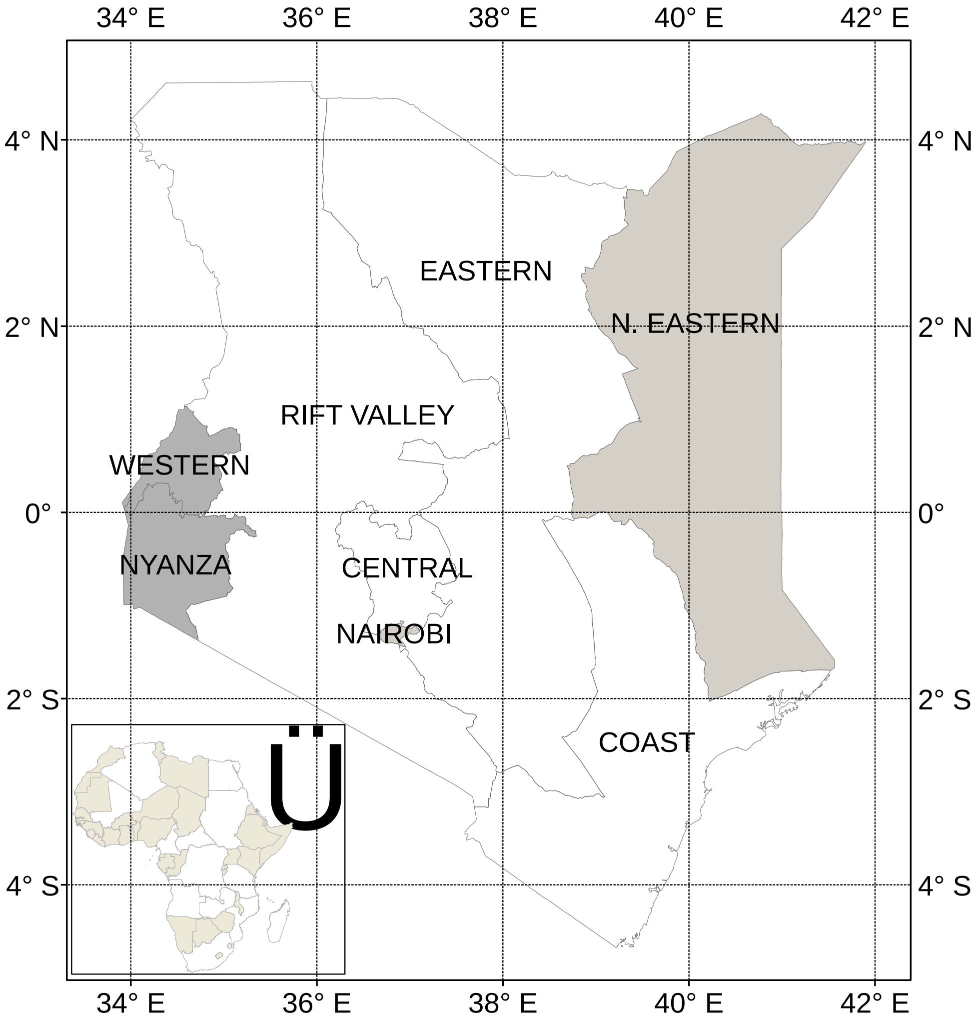


Figure 2.2 Map of the Republic of Kenya, showing study provinces.

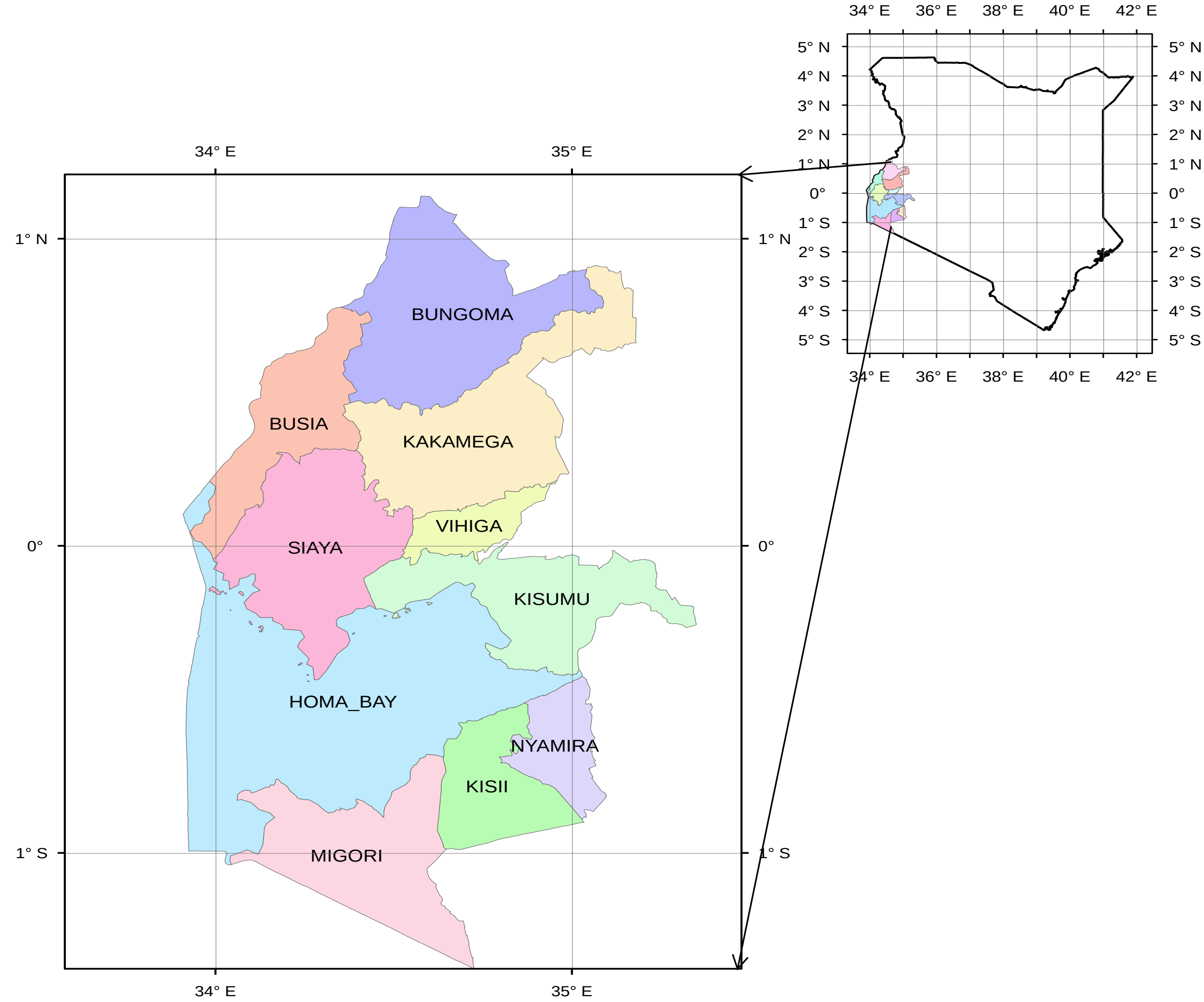


Figure 2.3 Map of the Republic of Kenya showing study districts.

2.3 Sampling method

A multi-phased sampling method was used in which the sample size of the Knowledge Attitudes and Practices (KAP) survey was first determined, after which sample sizes for the other stages were incrementally determined.

2.3.1 Study sampling frame and village selection steps

The process used to identify the study's sampling frame and to select study villages are shown in Table 2.4.

Table 2.4 Study sampling frame and village selection steps

Step	Action	Comment
1	Identify all provinces in which HWT had been implemented as a planned program	
2	Purposively select two provinces (Nyanza and Western) out of the eight identified	Basis of selection: a) Flood-prone nature. b) Variety of HWT methods promoted
3	Select intervening agencies that had promoted the HWT technologies which have been assessed globally for microbial efficacy (Sobsey *et al*., 2008), as part of a single program. (Biosand filter, ceramic filter, SODIS, Waterguard, Aquatab and PUR).	Kenyan Water and Health Association (KWAHO) and Safe Water and Poverty Project (SWAP) were identified as the two NGOs
4	A third NGO that had promoted ceramic filters was selected*	Women's Institute of Secondary Education and Research (WISER) was selected
5	Consequently, the sampling frame for the study was the completed study areas of SWAP, KWAHO and WISER.	KWAHO intervention: September 2009–August 2010 SWAP intervention: April 2007–October 2007, and April 2008 –April 2009.

*Because preliminary discussions with SWAP and KWAHO indicated that there were no Biosand filter, ceramic filter or SODIS users in the villages they had intervened in. All external support, monitoring and follow-up activities had ceased at least a year before the HWT study

2.3.2 Study sample size determination

The process by which the study sample size was determined for all the study stages is shown in Table 2.5.

Table 2.5 Study sample size determination steps

Step	Action	Comment
1	**KAP study and HWT adoption survey sample size determination**	
a	Fifteen out of the 74 intervention villages of the three agencies was determined as village sample size	Adapted from Garrett *et al*. (2008) as in Equation 1
b	Table of random numbers used to select 10 intervention villages from the sampling frame made up of the villages the three NGOs intervened in	
c	Two control villages purposively selected for each group of KWAHO and SWAP intervention villages by district and one control village for the WISER intervention	Basis of selection: a) control must belong to the same administrative unit as intervention; b) similar socio-economic conditions* c) geographical separateness#
d	Study sample size for households statistically derived as shown in equation 1	Sample size: 474 households in 10 intervention and five control villages (Lwanga and Lemeshow, 1991; Equation 2)
e	Sample size proportionally allocated to intervention and controls based on total number of households within villages; households surveyed selected using systematic random sampling (Table 2.6).	
2	**Water quality tracking**	
a	A table of random numbers was used to select six out of the 10 KAP intervention villages (Table 5.1)	(Two of four SWAP, three of five KWAHO, one of one WISER)
b	All the five KAP control villages selected (Table 5.1)	Two for SWAP, two for KWAHO and one for WISER intervention villages
c	One quarter of the KAP sample size used for water quality tracking household sample size (Table 5.1)	117 households
d	Sample size proportionally allocated to the 11 villages, based on total number of households in each village; households selected using systematic random sampling (Table 5.1).	117 households tracked in six intervention and five control villages. 291 water samples, 117 questionnaires
3	**HWT effectiveness & QMRA**	
a	List compiled of HWT method used (self-reported and observed during KAP survey)	
b	Five villages with at least eight users of at least one of the study HWT technologies were selected from the ten intervention villages from list of HWT methods used in study communities (Table 6.1).	37 households in five intervention villages were selected. 241 water samples, 98 questionnaires.

Similarities between intervention and controls further validated using various socio-economic indices (Table 2.2). The results of the matching are reported in the results section of Chapter Three. * Controls were not part of the villages that either of the NGOS had intervened in.

Derivation of sample size for number of villages

$$n = \frac{\{Z_{1-\alpha/2}\sqrt{p_0(1-p_0)} + Z_{1-\beta}\sqrt{p_a(1-p_a)}\}^2}{(p_a - p_0)^2}$$

Equation 1 (Lwanga and Lemeshow, 1991).

Where

$Z_{1-\alpha/2}$ = standard normal deviate at 95% confidence level = 1.96

P_0 = proportion of non-intervention villages with incidence of diarrhea in previous week= 0.12 (Adapted from Garrett *et al*., 2008)

P_a = proportion of intervention villages with incidence of diarrhea in previous week= 0.09 (Based on anticipated 30% reduction as used by Garrett *et al*., 2008)

$Z_{1-\beta}$ = standard normal deviate at power of 80% = 0.84

$$n = \frac{\{1.96\sqrt{0.12*0.88} + 0.84\sqrt{0.09*0.91})\}^2}{(0.3)^2}$$

n = 8

Adjusting for 80% response (i.e. data availability from villages), n = 8/0.8 = 10

With 95% confidence and power of 80%, a total of 10 intervention villages would be required to detect a 30% reduction in diarrhea incidence as a result of interventions. This is based on the premise that incidence of diarrhea is about 12% among under-5 children. The number of villages was increased from 10 to 15 to allow for a comparison between intervention and non-intervention (control) villages using a ratio of 2 intervention to 1 non-intervention (Garrett *et al*., 2008).

Derivation of sample size for KAP survey

This was derived as follows:

The sample size was calculated using the following expression (equation 2, Lwanga and Lemeshow, 1991):

$$n = \frac{z_\alpha^2 p * q}{d^2}: \qquad \text{Equation 2}$$

Where: z_α = standard normal deviate at 95% confidence level = 1.96

p = proportion of household with improved water source = 0.59 (WHO/UNICEF 2010)

q = 1-p

d = degree of precision = 5% = 0.05

$$n = \frac{1.96^2 * 0.59 * 0.41}{0.05^2}, \quad n = 372$$

Adjusting for an anticipated minimum response rate of 80%

$n_{adj} = 372/0.8 = 465$

In summary, the proportion of households with improved water sources in Kenya is 59% (WHO/UNICEF 2010). Using a confidence level of 95% and a 5% error margin, a sample size of 372 households was estimated for the KAP survey. This was increased to 465 in order to adjust for non-responses or attrition.

Table 2.6 Intervention and control villages, and sample sizes of KAP survey.

	Village	Province	District	Location	Sub location	No. of house holds	Sample size	Treatment
SWAP intervention villages								Boiling, cloth filtration, Alum, Waterguard, Aquatab, PUR
1	Kamahawa A	Nyanza	Nyando	Kahola	Ahero	534	72	
2	Kinasia	Nyanza	Nyando	East Kano	Katolo	229	49	
3	Kowino	Nyanza	Nyando	Onjiko	Kobongo	264	56	
4	Kokula A	Nyanza	Nyando	Wawidhi	Majina	261	55	
SWAP control villages								Boiling, Cloth filtration, Alum, Waterguard, Aquatab, PUR
1	Kabonyo	Nyanza	Nyando	Kakola	Kahola Ahero	96	20	
2	Kombura	Nyanza	Nyando	Awasi	Border 11	124	26	
KWAHO intervention villages								Boiling, Cloth filtration, Alum, Waterguard, Aquatab, PUR
1	Akado	Nyanza	Kisumu East	Central Kolwa	Nyalunya	145	31	
2	Angeyoni	Nyanza	Kisumu East	Central Kolwa	Nyalunya	84	18	
3	Kokumu	Nyanza	Kisumu East	Central Kolwa	Nyalunya	274	21	
4	Mudimbia	Western	Bunyala		Mabinju	105	62	
5	Khumwanda	Western	Bunyala		Mabinju	59	12	
KWAHO control villages								Boiling, Cloth filtration , Alum, Waterguard, Aquatab, PUR
1	Sigomere	Western	Bunyala		Mabinju	51	11	
2	Opuchi	Nyanza	Kisumu East	Central Kolwa	Kasule	42	13	
3	Rupia	Nyanza	Kisumu East	Central Kolwa	Kasule	52	8	
Ceramic filter intervention village								Ceramic filter,boiling, Cloth filtration, Alum, Waterguard, Aquatab, PUR
1	Tito	Nyanza	Migori	South East Muhuru Bay	Ibencho	22	20	
Total						2 342	474	
Pre-test village								
1	Odeso	Nyanza	Kisumu East	Kolwa Central	Kasule			

Number of households: Nyanza = 1 188 287; Western = 904 075; Nyando=78 225, Bunyala 66 723, Kisumu East = 115 502, Migori = 70 516

2.3.3 Inclusion criteria

Firstly, intervention villages were defined as those in which household water treatment had been promoted as part of a program, while control villages were those in which household water treatment had never been promoted as part of a structured program carried out by the government, an NGO or any other organisation. The use of household water treatment does not preclude inclusion in either the intervention or control groups. Secondly, participating households in the intervention villages must have been living in the village at the time of the KWAHO and SWAP HWT interventions. The selection criteria of the original KWAHO and SWAP HWT interventions was based on health facility data from the district headquarters showing cholera prevalence and the intervention was in areas with high cases of cholera.

2.4 Data collection methods

The methods used to collect data followed the recommendations of Tashakkori and Teddlie (1998) (Table 2.7). The study used a mixed-method approach to gather and interpret information. This method of social inquiry is one which uses multiple data gathering and analysis techniques to arrive at a better understanding of the study subject (Greene, 2007), in this case, the effectiveness of HWT in a real-world context. The mixed-method approach was selected because combining the methods retains their individual strengths but addresses the weaknesses each method has when used alone (Brewer and Hunter, 1989; Guba and Lincoln, 1994). In order to assess the effectiveness of the technical interventions within a social setting, it was important to first carry out surveys, i.e. the KAP and adoption of water treatment surveys using semi-structured questionnaires and focus group discussions. The survey method was chosen because it is cost-effective and because a relatively short time is needed to obtain information from a small sample and turn it into evidence of what happens in similar, though larger populations (Creswell, 1994). Thereafter the effectiveness of the technologies was assessed using water quality tests in conjunction with questionnaires. The tests were necessary to validate responses in the questionnaires, for example, whether the household treated water or not (Gomm, 2008).

At the end of the study, a Building a Case (BaC) method previously described by Suter and Cormier (2011) was used to arrive at the causes of the findings. Direct causes were those that had direct influence on the study hypothesis, while proximate causes were intermediate causes.

Table 2.7 Study objectives and study data collection methods.

	Objective	**Data collection**
1	Assess water, sanitation and hygiene related (WASH) knowledge, attitudes and practices of study households (Chapter 3). Provides contextual evidence of KAP factors that may affect HWT effectiveness.	Semi-structured questionnaires to obtain information about the knowledge, attitudes and practices of the study villages (Appendix 3.1).
2	Investigate the perceived value attached to HWT technologies and the likelihood of the adoption and compliance with household water treatment technologies (Chapter 4). Provides insight of HWT-user behaviour that may affect HWT effectiveness.	Semi-structured questionnaires to determine the perceived value of the HWT methods from the users' perspective (Appendix 4.1)
3	Assess water quality changes from source to the point-of-use and determine the point of highest degree of recontamination (Chapter 5). Indicates whether there is a need for HWT and the effect of KAP on water quality.	Physico-chemical and microbiological water quality tests to assess the changes in microbiological water quality from source to point-of-use and to determine the physical and chemical properties of the drinking water sources (Appendix 5.1)
4	Assess the effectiveness of selected household water treatment technologies (Chapter 6). Provides evidence of HWT effectiveness rather than efficacy under real-world conditions.	Physico-chemical and microbiological water quality tests supported by semi-structured questionnaires to assess the effectiveness of selected household water treatment technologies
5	Assess the change in risk of water-borne infections for HWT users of selected household water treatment technologies before and after treatment (Chapter 7). Indicates any health benefit of HWT at the observed levels of effectiveness	Physico-chemical and microbiological water quality tests and semi-structured questionnaires

2.5 Experimental procedures

The procedures used for water quality analysis and questionnaire administration are described here. The term microbiological quality or water quality refers in this thesis to the microbiological quality of drinking water, while physico-chemical quality refers to the physical and chemical characteristics of the drinking water. Heavy metal analysis was carried out in the Mines and Geology Department, Nairobi, Kenya, and analysis of other chemical parameters at the Kenyan Marine Fisheries Research Institute, Kisumu, Kenya

2.5.1 Measurements of drinking water physical parameters

Measurements of turbidity, pH, electrical conductivity and temperature were carried out on site. Turbidity was measured in the field using the Delagua Ltd turbidity tube as previously described by (Stevenson, 2008) and according to the manufacturer's instructions (Oxfam–Delagua, 2000). The drinking water sample was carefully poured into the turbidity tube until the point at which the black circle at the bottom of the tube could no longer be seen. Care was taken not to strain the eyes or introduce bubbles. The point at which the black circle disappeared was read from the Turbidity Unit (TU) marking on the side of the Delagua Turbidity Tube. The TU is designed to correspond to the Nephelometric Turbidity Unit (NTU) and has a lower resolution value of 5 TU which is approximately 5 NTU and a higher limit of 2000 TU (Oxfam-Delagua, 2000; Stevenson, 2008) making it suitable for the drinking water assessments in this study.

pH, temperature and electrical conductivity were measured *in situ* using the waterproof combined pH, electrical conductivity, temperature and Total Dissolved Solids meter (Hanna Instruments) included in the Delagua water testing kit (Oxfam-Delagua, 2000).

2.5.2 Measurement of chemical parameters

Residual chlorine

The free chlorine residual was tested *in situ* according to the manufacturer's instructions (Oxfam–Delagua, 2000). The water was collected by the household in their usual manner, and poured into the sterile cup provided in the Delagua kit after which the comparator cells were washed three times with the water that was to be analysed and the cell for free chlorine filled with the sample. One DPD No. 1 tablet was then dropped into the right hand cell, the lid replaced firmly and the tablet was allowed to dissolve and the colour to develop. Finally, the free chlorine residual concentration was read by holding the comparator up to the sunlight and matching the colour developed in the cells with the standard colour scale in the central part of the comparator. The colour represented the free chlorine residual in mg/l.

Total Dissolved Solids

Total dissolved solids (TDS) was determined using gravimetric methods according to approved standard methods number 2540-C (APHA, 2005), 100 ml of sample was filtered through a Whatman 934AH glass fibre filter, and evaporated to dryness at 180 °C to constant weight (APHA, 1999). TDS was calculated according to following equation (equation 2).

$$\text{mg total dissolved solids/l} = \frac{(A-B)*1000}{sample(ml)} \qquad \text{Equation 2}$$

where: A = weight of dried residue + dish, mg, and

B = weight of dish, mg.

Total suspended solids

Total suspended solids was determined using gravimetric methods according to approved standard methods number 2540-D (APHA, 2005). A well-mixed sample was filtered through a weighed Whatman 934AH glass-fibre filter and the residue retained on the filter was dried, cooled, desiccated at temperatures between 103 and 105 °C and weighed until a constant weight was obtained. The increase in weight of the filter represented the quantity of the total suspended solids.

Chlorides

Chloride was determined according to Standard Methods 4500-Cl^- B (APHA, 2005). One hundred ml of the sample was titrated with standard $AgNO_3$ titrant to a pinkish yellow end point. This was based on the principle that under neutral or alkaline conditions, potassium chromate can indicate the end point of the silver nitrate titration of chloride, and that silver chloride is precipitated before the formation of the red silver chromate. Analysis was done in triplicates and the average computed. The levels of chlorides were determined according to the equation 3:

mg Cl^-/l = $\frac{(A-B)*3540}{sample(ml)}$ Equation 3

where:

A = ml titration for sample, B = ml titration for blank, N = normality of $AgNO_3$

and mg NaCl/l = (mg Cl^-/l) * 1.65

Total hardness

Total hardness was measured using standard method number 2320-B-titrations (APHA, 2005). The sample was titrated with ethylene-diamine tetraacetic acid (EDTA) solution approximately 0–20 gpg range per 100 ml using Erichrome Black T, a sodium salt as an indicator. The EDTA chelates with metal ions such as magnesium or calcium to form a red coloured complex. Thus each drop of the reagent complexes with metal ions until the end point is reached where the colour changes from red to blue (APHA, 2005).

Total hardness was calculated as mg/l equivalent $CaCO_3$ according to equation 4:

Total hardness (EDTA), mg $CaCO_3$/l = $\frac{A*B*1000}{sample(ml)}$ Equation 4

where:

A = ml EDTA titrated for sample

B = mg $CaCO_3$ equivalent to 1.00 ml EDTA titrant

Alkalinity

Total alkalinity was determined using standard methods number 2320–B (APHA, 2005). One hundred ml of the sample aliquot was titrated with standardized H_2SO_4 using mixed bromcresol green-ethyl red as the indicator. The end point reached is an indication that the hydroxyl ions present in the sample due to the dissolution of the solutes (mainly bicarbonates, carbonates and hydroxides) have reacted with the standardized acid at that particular pH. The total alkalinity as calcium carbonate was then calculated as:

Total alkalinity, mg $CaCO_3$ = $\frac{A * N * 50000}{sample(ml)}$ Equation 5

where:

A = ml standard acid used and

N = normality of standard acid

Aluminium

Aluminium was determined by flame atomic absorption spectrophotometry (AAS model Varian Spectraa-10) according to standard methods Method 3111 D using the Atomic Absorption Spectrometry/Direct Nitrous Oxide-Acetylene Flame Method (APHA, 2005).

Manganese

Manganese was determined by flame atomic absorption spectrophotometry (AAS model Varian Spectraa-10) with an air-acetylene flame according to the Standard Method 3111 B. Atomic Absorption Spectrometry/Direct Air-Acetylene Flame Method (APHA, 2005).

Lead

Lead was determined by flame atomic absorption spectrophotometry with an air-acetylene flame (AAS model Varian Spectraa-10) according to the Standard Method 3111 B. Atomic Absorption Spectrometry/Direct Air-Acetylene Flame Method (APHA, 2005)

Nitrates and Nitrites

Nitrate–NO_3 was determined using the nitrate electrode method according to the Standard Method 4500-NO_3 D. (APHA, 2005). 10 ml of standard solution was transferred to a 50 ml beaker, 10 ml buffer added and stirred for two to three minutes. The electrode was immerses and reading in millivolts taken after one minute. The electrode was rinsed and blot dried and the procedure repeated for other standards and the sample.

2.5.3 Determination of drinking water microbiological quality

The process of assessing the efficiency of the HWT technologies is previously described by Stevenson (2008) in which the microbial counts of the same water sample were assessed before and after treatment and the percentage or log reduction ascertained. The samples were analysed for total coliforms and *E. coli* within 24 h of collection at the Great Lakes University, Kenya laboratory using the membrane filtration technique (APHA, 2005). One hundred ml of samples were passed through a 0.47 mm diameter, 0.45 µm membrane filter (Millipore Corporation, Bedford, Massachusetts, USA) and inoculated on sterile absorbent pads impregnated with m-ColiBlue24 medium (HACH, USA) as previously described by Kerigan and Yeager (2009). Prepared cultures were placed in sealed petri dishes within 30 minutes of filtration and incubated for 24±2 h at $35^oC±0.5^oC$ in an Oxfam Delagua portable dual incubator model no. DWT 10099. Negative controls were also incubated, one consisting of sterile water processed in the same manner as the samples and the other was the sterile absorbent pad filter impregnated with m-Coli blue broth without the sample. When a volume of 100 ml produced a number of blue colony-forming units (CFU) that were too numerous to count (TNTC), the count was recorded as TNTC and assigned the average value of the batch of samples for the same type of source for purposes of statistical analysis of the total coliform and *E. coli*/100 ml as adapted from Clasen and Bastable, (2003).

Logistical limitations of the research setting precluded the analysis of replicate microbiological samples of varying dilutions. In order to limit the number of too numerous to count (TNTC) results, if a sample was considered by visual inspection to be turbid and likely to give a TNTC result, a serial dilution of 1:10 was used and, if very contaminated, a 1:100 dilution was used. All reagents and consumables used for microbiological and chemical analysis were of analytical grade and supplied by Kenlab, Kenya, with the exception of m-ColiBlue24 medium (HACH, USA), which was purchased from Great Lakes University, Kenya through Emory University, USA.

2.5.4 Water sampling methods

Samples were collected in 500 ml sterile whirl packs (Nasco International, Inc., Ft Atkinson, WI, USA) and stored in cooler boxes on ice till processed. Samples from sources were collected in a manner that most closely resembled the collection pattern of the communities (Clasen and Bastable, 2003; Mclaughlin *et al.*, 2009). Taps and borehole outlets were not flamed as described by Clasen and Bastable (2003), surface water source samples were collected at the point at which the households fetched the drinking water sources, while rainwater was collected from the harvesting container using a sterile metal collection container which was rinsed three times with the source water. The samples from the collection containers were collected by decanting into the sterile containers. The samples from the drinking water storage container were collected from the storage container which the youngest child drank from on the day of the sampling. The respondent was asked to use their usual container to take water from the container, which was then poured into sterile sampling bags for assessment in the laboratory. The triplicate samples were coded with unique identification numbers for the specific households, as well as village, location, and source codes. This was done to facilitate matching as well as to ensure that the laboratory analysis was blind.

Unannounced visits were paid to each of the selected households between April and May, 2011 to collect water samples at the source, collection and storage points. The water quality deterioration was tracked with water samples collected during a single sampling visit, while the HWT effectiveness assessments were carried out with samples collected during three sets of visits.

2.6 Statistical analysis

Household survey results were recorded in hardcopy and entered into digital forms using Excel (Microsoft Corp., Redmond, WA). All statistical analyses were done using SAS software (SAS for Windows version 9.1, SAS, Cary, North Carolina, USA). Justification for statistical methods used

Knowledge, attitude and practices of respondents in relation to water, sanitation and hygiene were compared between the intervention and control communities using the Chi-square goodness of fit test and the Fisher’s exact test (Chapter 3). The Fisher’s exact test was used when sample sizes were considered small. Both tests were used because they are best suited for nominal data (Marques de Sá, 2007). The Fisher’s exact test was also applied to test whether statistical significance exist between the control and intervention communities in terms of respondents’ perception of water treatment technologies, their adoption and sustained use (Chapter 4).

Frequencies and means were used to assess the perceived value attached to HWT by user households. Logistic regression was used to determine whether a significant relationship exists between respondents' perceptions, adoption, sustained use, and the different treatment technologies for both the control and the intervention communities (Chapter 4). The added advantage of regression is that variables which are potentially confounding can be included and adjusted for. The data were coded in binary form and thus the use of binary logistic regression. Binary logistic regressions were also performed to test the association between knowledge, attitudes and practices and the outcome of water quality (Chapter 5).

One-way analysis of variance (ANOVA) ($P < 0.05$) was used to compare whether treatment technologies differ in effectiveness for both the improved and unimproved water sources in a post-implementation period (Chapters 6). Since ANOVA is a parametric statistics that assumes normality data and homogeneity of variance (Ogbeibu, 2005), data were log-transformed (log reduction) to approach these assumptions. When ANOVA indicated global statistically significant differences between technologies, a Tukey's Honestly Significant Different (HSD) test was used to indicate technologies that differed significantly. However, when there are unequal numbers of sample sizes between technologies, the Least Significant Different (LSD) test was applied. Unlike the Tukey's HSD test, LSD can be used when samples sizes between groups are not equal (Ogbeibu, 2005). Differences in the means of drinking water quality variables between sources and point-of-use (POU) for both unimproved and improved sources were elucidated using one-way ANOVA (Chapter 5). The probability of the risk of infection with water-borne pathogens (using *E. coli* as an indicator) in the intervention communities was compared between technologies using unimproved and improved water sources with one-way ANOVA (Chapter 7). The odds ratio was also used as a measure of the likelihood of risk of a particular outcome in an exposed group in comparison to the unexposed group. For instance, to assess the difference in risk of having poor water quality in households that use improved water sources and those that use unimproved water sources. Though multivariate analysis such as regressions (Black *et al*., 2007) could have been used to integrate the study components, the study chose to use a Building a Case from lines of evidence approach (Suter and Cormier, 2012). Binary logistic regressions were thus used within chapters to obtain the required lines of evidence.

2.7 Ethical and legal considerations

This study was reviewed and approved by the Research Ethics Committee of the Rhodes University, South Africa and local permission secured as a result of the partnership with the Environmental Health Unit, Maseno University, Kenya, UNICEF Kenya and the Government of Kenya. The study objectives, the potential information to be obtained from the households, the intended use of the study in relation to publications and policy recommendations, were clearly explained to stakeholders such as the Kenyan National Technical Working Committee on HWT, Kenyan Inter-agency Collaborating Committee on Water and Sanitation, the administrative chiefs of the selected locations as well as the study respondents. Informed consent was obtained from the study respondents in writing and the proposed participants were also informed that even after giving their consent, they could at any stage withdraw from the study with no adverse effect to the study or themselves.

3 KNOWLEDGE, ATTITUDES AND PRACTICES AND POTENTIAL EFFECT ON WATER QUALITY

3.1 Introduction

This chapter gives an overview of the socio-demographics of the study households and their water, sanitation and hygiene knowledge, attitudes and practices (KAP). It contributes to the overall aim by providing a contextual basis for the assessment of the effectiveness of household water treatment (HWT) technologies in real-world conditions.

Safe water provision is one of the environmental health interventions used to prevent water and sanitation-related diseases (Fewtrell and Colford, 2004). Recontamination of water supplies can however reduce the health benefits of improved water supply provision (Wright *et al*., 2004). A systematic review of 57 water and sanitation studies carried out by Wright *et al.* (2004) in Western, Eastern, Southern and Northern Africa as well as parts of Asia, Southern and Central America attributed such contamination to the setting in which the water sources were provided. These authors used indices such as the knowledge, attitudes and hygiene practices of the communities as they collect, transport and store water to give examples of how the setting or context can recontaminate drinking water. Examples of such practices include not washing hands with soap (Onabolu *et al.*, 2011). After a systematic review of 17 studies in parts of Africa, Asia America and Australia, Curtis and Cairncross (2003) observed that handwashing can reduce the risk of diarrhoeal diseases by 47%.

Tumwine (2005) pointed out that water from an improved source can become recontaminated if not stored properly. Storage practices that may contribute to recontamination are the use of uncovered collection and storage vessels (Mintz *et al*., 1995; Gasana *et al*., 2002, Wright *et al*., 2004; Levy *et al.,* 2008); transferring water from a collection container into a different storage container (Lindskog and Lindskog, 1987 and Clasen and Bastable, 2003); the use of wide-mouthed storage containers (Mintz *et al*., 1995; Levy *et al.,* 2008), dipping hands into storage containers and handling water with faecally contaminated hands (Roberts *et al*., 2001; Trevett *et al.,* 2005). Biological processes within the storage container such as bacterial growth and presence of biofilms may also lead to deterioration of stored water quality (Momba and Notshe, 2003 and Jagals *et al.,* 2003).

Poor sanitation practices were associated with poor water quality (Galiani and Orsola-Vidal, 2010) while the practice of household water treatment and the use of an improved source were positively associated with good water quality (Levy *et al.*, 2008; Onabolu *et al.,* 2011). However poor knowledge about household water treatment methods (Onabolu *et al.,* 2011) and poor attitudes towards sanitation such as not attaching a stigma to open defecation (Banda *et al.*, 2007) may also cause recontamination.

Socio-demographics have also been linked to the recontamination of drinking water and the creation of an environment that is conducive for the transmission of diarrhoeal and water-borne diseases. Galiani and Orsola-Vidal (2010) found that there was an inverse relationship between income level and the distance of the handwashing facilities to a house, and an inverse relationship between income level and the *Escherichia coli* count in drinking water and hand-rinse samples. The non-reticulation of water to individual household taps and the dependence on communities for proper operation and maintenance to deliver safe water consistently, has also been given as reasons for recontamination (Bryce *et al.*, 2005).

In addition to understanding the knowledge, attitudes and practices which may lead to recontamination of improved water supplies, it is important to understand the factors that facilitate the use of safe water supplies. Whereas the drinking water supply and sanitation sector maintains that water quality is the most important factor to users, users themselves rank convenience the highest, and observed practices indicate that users may neglect safe water sources for closer but more polluted sources (Younes and Bartram, 2001).

Users may rate convenient access to their water source highly because they are aware of the time they can save for more productive activities. Hutton and Haller (2004) carried out a global study to determine the costs and benefits associated with various water and sanitation interventions and found that the main benefit of improved access to water and sanitation was the time saved.

Though studies have been carried out to examine the effect of inadequate knowledge, inappropriate attitudes and practices of users on the deterioration of drinking water quality, very few of those studies have been carried out as part of the process of examining the effectiveness of household water treatment technologies under typical-use conditions. This chapter examines the water, sanitation and hygiene-related knowledge attitudes and practices (KAP) of the study communities (intervention group and control group), and the potential behavioural causes of contamination and water quality deterioration within these communities. A questionnaire was developed to elicit information about water, sanitation and hygiene related KAP variables that literature suggests may lead to contaminated drinking water contamination and deteriorating water quality (Appendix 3.1). The KAP indicators are summarised in Table 3.1

Table 3.1 Variables used to examine KAP of intervention and control communities (Roberts *et al*., 2001; Younes and Bartram, 2001; Curtis and Cairncross, 2003; Hutton and Haller, 2004; Wright *et al*., 2004; Bryce *et al*., 2005; Banda *et al*., 2007; Galilani and Orsola-Vidal (2010); Onabolu *et al*., 2011)

	Knowledge			**Attitudes**			**Practices**			
Definition	The information, understanding and skills that you gain through education or experience (Hornby *et al* ., 2005)			The way that you think and feel about somebody/something; the way that you behave towards somebody/something that shows how you think and feel (Hornby *et al.*, 2005)			A way of doing something that is the usual or expected way in a particular situation or organisation (Hornby *et al* ., 2005)			
Area of assessment	**Water**	**Sanitation**	**Hygiene**	**Water**	**Sanitation**	**Hygiene**	**Water**	**Sanitation**	**Hygiene**	**Other**
Topic	Water quality and health	Sanitation and health	Hand washing with soap	Expected quality of potable water	Willingness to pay to construct improved toilet	Critical time to wash hands with soap	Sources used for various purposes	Type of toilet used if any	Practices after defecation	Household membership of various community groups
	Quality of potable water	Sanitation and water quality	Water and health	Water treatment and water safety	Importance and reason for paying for an improved toilet		Sources used in different seasons	Place of defecation	Practices after child defecation	
	Benefits of water treatment	Distance between toilet and water source		Reason for use and satisfaction with main drinking water source			Distance and time taken to source used	Place of defecation of youngest child	Water storage and handling	
							Drinking water quantity of households	Disposal of child faeces	Evidence of soap in the house and near toilet,	
							Treatment of household water, method, frequency and routine use			
							Treated water consumption at home and when away from home			
							Channel of hearing about water treatment method			
							Operation and maintenance of improved source			
							Gender roles in water management			
							Length of time main drinking water source has been used			

3.2 Methods

3.2.1 Description of study area

The study area has been previously described in Chapter Two, section 2.2

3.2.2 Sampling method and sampling size

A knowledge, attitudes and practice (KAP) cross-sectional survey was conducted during the non-rainy season from March to May 2010 in the Nyanza and Western provinces of Kenya. The sampling method and sample size determination has been described in Section 2.4.1

A total of 474 households were visited for data collection and this sample was allocated proportionally to the 10 intervention villages and five controls villages according to the number of households in the 15 villages (Table 2.6).

3.2.3 Data Collection

The researcher, assisted by a team made up of a laboratory manager, two water and sanitation project managers, trained ten research assistants on theoretical and practical components of the study. They were trained how use tools such as the KAP and HWT adoption questionnaires, the Geographical Positioning Systems (GPS), the pH and conductivity meters as well as the various HWT technologies that the study aimed to assess.

After the training, the interviewers collected qualitative and quantitative information using a pre-tested semi-structured questionnaire combined with an observational checklist (Appendix 3.1). The caregiver of the youngest child in the house was selected as respondent (‘child’ was defined as a person below 18 years). Where there was no child in the house, the household head was interviewed. In some instances; the household head preferred that the oldest female in the house was interviewed.

The KAP questionnaire (Appendix 3.1) was designed to elicit information that literature indicates is relevant to water quality and household water The questionnaire was structured to gather water, sanitation and hygiene-related information about the intervention group and control group populations such as socio-economic and demographic characteristics, access to water, sanitation and hygiene facilities and the sanitation practices of children aged below five years (Appendix 3.1). Other information gathered included sanitation-related knowledge and hygiene practices, gender roles in relation to water collection and treatment; water consumption patterns and expectations of safe drinking water quality; water treatment communication channels, and practices and disease-related knowledge, attitudes and diarrhoeal incidence

The questionnaire was validated by observing the type of water, sanitation and handwashing facilities, availability of soap for handwashing, conditions of the water and sanitation facilities and the water storage practices (Appendix 3.1). The KAP questionnaire was pre-tested in Odeso, a village similar to the intervention villages and the errors detected were corrected before conducting the KAP survey.

3.3 Data analysis

Data was analysed as described earlier in Section 2.7

3.4 Results

The results are presented in the following order: the setting of the study, similarities (matching) between the IG and CG villages, particularly in relation to confounding factors (confounders are those characteristics which the study outcomes might be attributed to if they differed significantly between the two study group); the socio-economic and demographic patterns of study and control households, and the water, sanitation and hygiene-related knowledge, attitudes and practices of the IG and CG households. This is followed by the monetary value of the opportunity costs of inadequate access to safe drinking water, and the identification of the knowledge, attitudes and practices that may cause water quality deterioration between the source and the point-of-use.

3.4.1 Overview of control and intervention villages

A total of 474 households were interviewed, 397 (83.76%) from 10 intervention group (IG) villages and 77 (16.24%) from five control group (CG) villages. Table 3.2 indicates that the IG and CG villages are well matched with only two out of the 20 variables used to compare the IG and CG showing a statistically significant difference. They were *hearing about drinking water* *treatment method through an NGO* ($p < 0.0001$; OR: 5.47; 95% CI: 3.05–9.83) and mean *household sizes* which was six in the IG and five in the CG ($p < 0.0005$) (Table 3.2). The IG and CG were well matched in the potentially confounding variables such as education, employment and poverty, signifying that the setting had not been altered as a result of the intervention and that the results of the intervention can be interpreted and generalised within a context that is common to other rural communities in the Western and Nyanza provinces of Kenya (Table 3.2).

. **Table 3.2** Matching of control and intervention villages

	Variable	Total Frequency	Intervention		Control		p value	OR	95% CI
			Frequency	%	Frequency	%			
1.	Female: Male (KAP) ratio [a]	474	397	14:11	77	6:1	0.887	N/A	N/A
2.	Mean stay in community (years)[b]	474	397	19.80 y	77	20.46 y	0.886	N/A	N/A
3.	Respondent's average age (years)[b]	474	397	39.61±15.84	77	40.62±17.47	0.60	N/A	IG = 38.04─1.17 CG = 6.66─4.59
4.	Marital status(married)	474	397	70.53	77	59.74	0.116	N/A	N/A
5.	Employment of KAP respondent	474	32	8.06	11	14.29	0.086	0.52	0.25–1.10
6.	Unemployment of KAP respondent	474	365	91.94	66	85.71	0.086	1.9	0.9─4.0
7.	Unemployment of household head	474	28	7.05	8	10.39	0.35	1.5	0.67─3.5
8.	Employment of household head	474	369	92.95	69	89.61	0.35	0.65	0.29─1.5
9.	Adopter profile of household head (credit group)	295	247	62.69	48	62.34	0.953	1.01	0.61─1.68
10.	Adopter profile of household head (female/male group)	316	265	67.43	51	66.23	0.838	1.06	0.63─1.78
11.	Adopter profile of household head (religious group)	341	288	73.28	53	68.83	0.424	1.24	0.73─2.11
12.	Adopter profile of household head (burial committee)	163	137	34.86	26	33.77	0.854	1.05	0.63─1.76
13.	Mean age of youngest (years)[b]			5.16		5.49	0.404	N/A	N/A
14.	Poor households[c]	474	252	63.48	42	54.55	0.140	1.45	0.9─2.4
15.	Dominant floor material (earth mud)	423	353	88.92	70	90.91	0.615	N/A	N/A
16.	Non thatched roof material (iron/tile)	408	346	86.90	62	80.52	0.196	N/A	N/A
17.	Hearing of drinking water treatment method through NGO	474	234	58.94	16	20.78	0.0001	5.47	3.05─9.83
18.	Water treatment respondents without education	474	38	9.64	7	9.09	0.914	N/A	N/A
19.	Households with under 5 year old children	474	228	57.43	48	62.34	0.424	0.82	0.49─1.35
20.	Mean household size	474	6.06±2.83	N/A	4.86±2.30	N/A	0.0005	N/A	# 5.78─6.34 ¥ 4.34─5.38

[a] ratio not percentage; [b] year not percentage; [c] Economic assessment: of a total of 7 household assets, ownership of 0–1 = very poor; 2–3 = poor and 4–6 = not poor;; # 95% CI of mean of interventions; ¥ 95% CI of mean of controls; Adopter profile:; quantification of adoption potential of household heads using proxy indicators *: statistical significance at $p \leq 0.05$; y: years

3.4.2 Socio-economic and demographics

Description of the study households

The average household size was 6.06±2.83 and 4.86±2.30 persons in the IG and CG respectively, with majority of household members falling between the ages of 5 and 14 in both study arms. Most of the households in both study arms had children aged below 5 years. The IG had 382 (96.22%) and the CG had 72 (93.50%). Table 3.2 shows that these children came from 228 (57.43%) and 48 (62.34%) households in the IG and CG respectively. The study households had been in the village for an average period of about 20 years in both study arms (19.80 years in the IG and 20.46 years in the CG).

Table 3.3 shows that when ownership of household assets such as fridges, televisions, cell phones, bicycles was used as assessment criteria, more than half of the households in both study arms were poor: 252 (63.48%) in IG and 42 (54.45%) in CG, because they owned only two or three of the household assets. When ownership of land was used as the criterion most households in both study arms were not poor, with 391 (98.49%) in IG and 76 (98.70%) in CG reporting that they own the land they live on. Figure 3.1 shows some of the community members.

Table 3.3 Economic profile of the study households.

	Intervention		**Control**	
Variables	Frequency	%	Frequency	%
Very poor	127	31.99	32	41.56
Poor	252	63.48	42	54. 54
Not poor	18	4.53	3	3.90
Total	397	100	77	100

Study household economy was assessed using ownership of household assets. Of a total of 7 assets, ownership of 0–1= very poor; 2–3 = poor and 4–6 = not poor

Figure 3.1 Study community members.

Description of the respondents

The KAP respondents were mainly female in both IG and CG, in a female: male ratio of 14:1 and 6:1 respectively (Table 3.2). The median age of the respondents was 38 years in both study groups, while the mean age of the respondents was 39.61±15.84 and 40.42±17.40 years in the IG and CG respectively. Most of the respondents were married (70.53% in IG and 59.74% in CG) and were predominantly Christian 359 (90.43%) in IG and 74 (96.12%) in CG. They were mainly Luo-speaking people, with 355 (89.42%) in IG and 61 (79.22%) in the CG. (Table 3.4)

Those responsible for keeping water clean in both study arms were mostly spouses of household heads 259 (65.24%) in IG and 40 (51.95%) in CG, while some were household heads themselves 112 (28.21%) in IG and 32 (41.56 %) in CG (Appendix 3.2). In terms of education, only three (0.76%) of the KAP respondents in the IG and none of the CG had attended university or polytechnic and very few had completed secondary school in the two study arms i.e. 26 (6.55%) in IG and 7(9.09%) in CG (Appendix 3.3).

Most of the respondents were employed with only 32 (8.07%) in IG and 11(14.29%) in CG not working. Though income levels were not determined, the asset assessment indicated that they were poor, as the predominant occupations also suggested. The predominant occupations in both study arms were subsistence farming by 206 (51.59%) in IG and 31(40.26%) in CG, followed by self-employed businesses 105 (26.45%) in IG and 30 (38.96%) in CG (Appendix 3.4). There was no significant difference between the IG and CG in the unemployment status of either the KAP respondents or the household heads (as earlier shown in Table 3.2).

Table 3.4 Socioeconomic characteristics of respondents.

Variable	**Intervention**		**Control**	
	Frequency	%	Frequency	%
Gender of KAP Respondents n = 474				
Male	26	6.55	11	14.29
Female	371	93.45	66	85.71
Total	397	100	77	100
(P = 0.02; OR: 2.378; 95% CI : 1.12–5.05)				
Marital status				
Single	28	7.05	6	7.79
Married	280	70.53	46	59.74
Divorced/separated	2	0.50	2	2.60
Widowed	87	21.91	23	29.87
Total	397	100	77	100
Religion				
Christian	359	90.43	74	96.1
Other	38	7.57	3	3.90
Total	397	100	77	100
Age				
Median	38 years		38 years	
Mother tongue of KAP respondents				
Luo	355	89.42	61	79.22
Luhyia	35	8.82	12	15.59
Kikuyu	4	1.01	1	1.3
Kiswahili	1	0.25	1	1.3
English	0	0	1	1.3
Others	2	0.50	1	1.3
No of households with children <5 years	228	57.43	48	62.34
Mean household size	6.06±2.83		4.86±2.30	95% CI: IG = 5.78–6.34; CG = 4.34–5.38

KAP: Knowledge attitude and practice; IG: intervention group; CG: control group

Description of the household head

Most of the household heads were male in a 1:3 and 1:2 female:male ratio in the IG and CG villages respectively (Table 3.5). As observed with the KAP respondents, very few household heads in either study arms were unemployed (28 (7.11%) in IG and 11 (14.29%) in CG), though, like the KAP respondents, the predominant occupations were unlikely to generate high income levels. Occupations were: working on their own farms by 148 (37.28%) in IG and 26 (33.77%) in CG, or were self-employed in small businesses: 114 (28.72%) in IG and 25 (32.47%) in CG (Table 3.5).

Table 3.5 Selected socio economic characteristics of the household heads.

Variable	**Intervention**		**Control**	
	Frequency	%	Frequency	%
Gender of household head (n = 474)				
Female	103	25.94	23	29.87
Male	294	74.06	54	70.13
Total	397	100	77	100
Male : Female ratio (p = 0.48; OR: 1.22; 95% CI : 0.17–2.08				
Occupational status of household head (n= 474)				
Working on farm only	148	37.28	26	33.77
Self employed business	114	28.72	25	32.47
Skilled artisans	53	13.35	8	10.39
Driver	5	1.26	1	1.30
Not working and not looking	25	6.30	5	6.49
Looking for work	3	0.76	3	3.90
Teacher/lecturer	11	2.77	2	2.60
Domestic worker for pay	8	2.02	2	2.60
Retired by age with pension	7	1.76	1	1.30
Retired by age not on pension	6	1.51	1	1.30
Civil servant	7	1.76	1	1.30
Construction	4	1.01	0	0.00
Work on others farm for wage labour	2	0.50	2	2.60
Pastor	1	0.25	0	0.00
Housewives	1	0.25	0	0.00
Cyber café attendant	1	0.25	0	0.00
Watchman	1	0.25	0	0.00
Total	397	100	77	100

Appendix 3.5 shows that the household heads share a similar educational profile with the KAP respondents: very few had tertiary education, and only 15% in both study arms had completed secondary school. Most of household heads, like the KAP respondents, had some form of education, with only 42 (10.58%) in IG and 9 (11.69%) in CG not having any education at all. As was observed with the KAP respondents, the predominant level of education was primary school completion in both study arms 120 (30.23%) in IG and 27 (35.06%) in CG.

The findings indicated that at least two-thirds of the household heads in both IG and CG were members of men or women's group, or a religious group, (Table 3.6).

Table 3.6 Suggested adopter profile of the household heads of study households.

Variables	**Intervention**						**Control**						**Intervention**		**Control**	
	Yes		No		Don't know		Yes		No		Don't know		Total		Total	
Membership of group	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
Gender based group	265	66.8	128	32.2	4	1	51	66.2	26	33.8	0	0	397	100	77	100
Credit, saving or insurance group	247	62.2	147	37	3	0.8	48	62.3	29	37.7	0	0	397	100	77	100
Organized religious group	288	72.5	105	26.5	4	1	53	68.8	24	31.2	0	0	397	100	77	100
Burial committee	137	34.5	256	64.5	4	1	26	33.8	51	66.2	0	0	397	100	77	100
A community group different from above	11	2.77	384	96.7	2	0.5	2	2.6	75	97.4	0	0	397	100	77	100

3.4.3 Water, sanitation and hygiene knowledge, attitudes and practices

Water, sanitation and hygiene facilities

Water sources

Figures 3.2–3.4 show some of the improved and unimproved sources used by the study communities. Only about one in two of the households in both IG and CG used improved water sources as their main drinking water source in the non-rainy season: 234 (58.95 %) in IG and 46 (57.13%) in the CG indicating a need for effective household water treatment (Figure 3.5). There was no significant difference between the IG and CG in the use of improved and unimproved sources in the non-rainy season (p = 0.77) or in the rainy season (p = 0.81).

Figure 3.2 Examples of unimproved sources: surfacewater (left), handdug well right).

Figure 3.3 Improved sources: Handpump-fitted borehole.

Figure 3.4 Improved sources: rainwater collection into tank and storage container.

The study’s findings on access to water are based on the current classification of rainwater as improved by the Joint Monitoring Programme. However, because WHO (2008) noted that rainwater can be contaminated during collection from bird droppings and other dirt from the collecting surface, this study created four scenarios to show the access figures when rainwater is classified as improved and unimproved (Table 3.7). The study then determined the actual quality of rainwater (Chapter Five).

Table 3.7 Use of improved and unimproved water sources based on the classification of rainwater as either an improved or unimproved water sources.

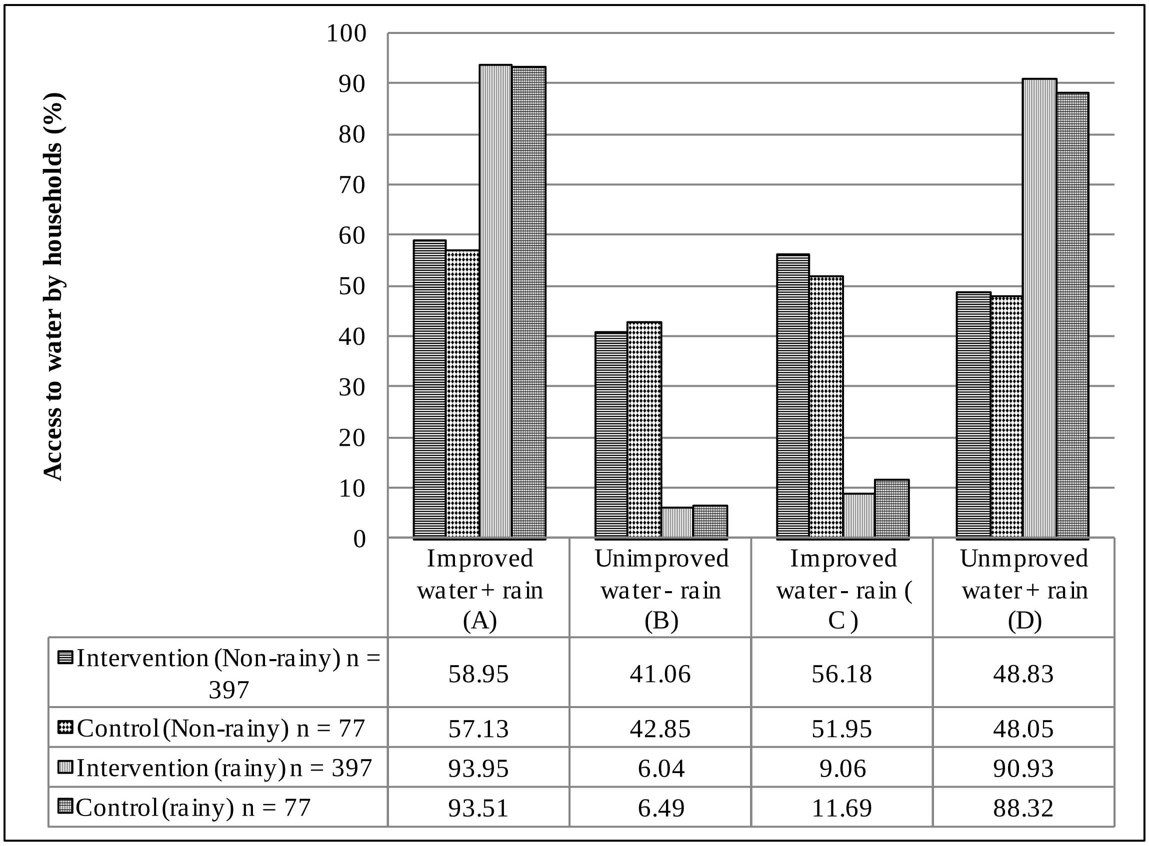
Scenario	Description of the scenario
A	The use of improved water during the non-rainy and rainy season with the inclusion of rain as an improved source. (Figure 3.5, improved water + rain).
B	The use of unimproved water during the non-rainy and rainy season with the exclusion of rain according to the JMP definition (Figure 3.5, unimproved water - rain).
C	The use of improved water during the non-rainy and rainy season with the exclusion of rain in the improved source category. (Figure 3.5, improved water - rain)
D	The use of unimproved water during the non-rainy season and the rainy season with the inclusion of rain in the unimproved source category. (Figure 3.5, unimproved water + rain).

Figure 3.5 indicates that there was no difference in the pattern of use between the IG and CG in any of the four scenarios. During the non-rainy season, there was no difference between the current JMP scenario A (improved water + rain) and the hypothetical scenario D (improved water without rain). Half the IG and CG would use improved water sources whether rainwater was included in the improved category (A) or not (D).

Similarly, scenarios B and D are similar in the non-rainy season with about 40% in both IG and CG using unimproved water if rainwater was excluded as the JMP currently does (B: unimproved - rain) and about 48% using unimproved sources if rainwater was included hypothetically. (D: unimproved water + rain).

However during the rainy season, because of the increased dependence on rainwater, the classification of rainwater makes a difference to the figures of use of improved and unimproved sources. For example, scenarios A and C are clearly different with 93% in both study groups having access to improved water if rain is included in this category (scenario A) or only about 10% in both groups if rainwater is excluded (Scenario C).

Similarly, scenarios B and D differ, with about 6% of households using unimproved water if rainwater is excluded as the JMP currently does (scenario B: unimproved - rain) and about 90% using unimproved sources if rainwater is included in this category (scenario D: unimproved water + rain).



	Improved water+ rain (A)	Unimproved water- rain (B)	Improved water- rain (C)	Unmproved water+ rain (D)
▤ Intervention (Non-rainy) n = 397	58.95	41.06	56.18	48.83
⊞ Control (Non-rainy) n = 77	57.13	42.85	51.95	48.05
▥ Intervention (rainy) n = 397	93.95	6.04	9.06	90.93
▦ Control (rainy) n = 77	93.51	6.49	11.69	88.32

Figure 3.5 The use of improved and unimproved water sources as main drinking water source.

The types of sources were further examined using the current JMP classification of improved and unimproved water sources. The improved water sources were mostly decentralised with only four (1.01%) IG and no CG households using yard/ household level connections as their major water source (Table 3.8). The use of yard/household connections decreased even further during the rainy season with only two (0.5%) households in IG and none in the CG using these sources. (Table 3.8).There was a decrease in the use of all types of water sources except rainwater during the rainy season. For example, of those using improved water sources, about 1 in 20 households in both study groups used motorised boreholes as their main drinking water source. This proportion however decreased to 1 in 400 households in the IG and no users in the CG during the rainy season (Table 3.8). Public standpipe users, for example, decreased from 74 (18.64%) in IG and 12 (15.55%) in CG in the rainy season to 10 (2.52%) and 1 (1.30%) in IG and CG households respectively. The same trend can be observed for handpump-fitted boreholes, protected dug wells with and without handpumps. Conversely, rainwater use increased from 11 (2.77%) in IG and 4 (5.19%) in CG households in the non-rainy season to 334 (84.89%) and 63 (81.82%) during the rainy season in IG and CG respectively. Surface water was the major source of unimproved water use during the non-rainy season; however its use decreased seven-fold in both groups in the rainy season (Table 3.8).

Table 3.8 Drinking water sources used by the households during the non-rainy and rainy season.

Variable	**Main water source in non-rainy season**				**Main water source during rainy season**			
Use of water sources by households (n = 474)	Intervention		Control		Intervention		Control	
	Freq	%	Freq	%	Freq	%	Freq	%
Piped water into apartment	3	0.76	0	0.0	2	0.50	0	0
Piped water into compound	1	0.25	0	0.0	0	0	0	0
Motorized borehole	21	5.29	4	5.19	1	0.25	0	0.00
Public stand pipe	74	18.64	12	15.55	10	2.52	1	1.30
Handpump borehole	37	9.32	9	11.69	7	1.76	3	3.90
Protected dug well with handpump	42	10.58	11	14.29	9	2.27	5	6.49
Protected dug well without handpump	45	11.34	4	5.19	7	1.76	0	0.00
Unprotected handdug well	12	3.02	0	0.00	2	0.50	0	0.00
Developed spring	-	-	-	-	0	0.00	0	0
Undeveloped spring	-	-	-	-	1	0.25	0	0
Rainwater	11	2.77	4	5.19	337	84.89	63	81.82
Sachet water	-	-	-	-	0	0	0	0
Tanker vendor	-	-	-	-	0	0	0	0
Surface water	151	38.04	21	27.27	21	5.29	3	3.90
Wheelbarrow vendors	0	0.00	12	15.58	0	0	2	2.60
Total	397	100.00	77	100.00	397	100.00	77	100.00

Sanitation

Very few respondents, about 1 in 10 of the IG reported that they possessed or used improved sanitation facilities. The picture was the same in the CG with only 1 in 10 having, and 1 in 12 using improved sanitation. There was no statistical difference between the two study groups in the availability of either improved or unimproved categories of sanitation facilities within the households (Table 3.9).

The study assessed the type of improved and unimproved sanitation facilities used (Table 3.9). Though open defecation was reportedly practiced by just 3% in the IG and by 18.18% of CG, the proportion of those practicing open defecation was about six times higher in the CG than in the IG, with a highly significant difference observed between the study groups ($p < 0.0001$; OR = 0.12; 95% CI: 0.05–0.27). A statistically significant difference was also obtained with regard to not having facilities in the household. The IG was less likely to have no facility ($p < 0.0001$; OR: 0.12; 95% CI: 0.04–0.35) than the CG. Traditional pit latrines were the predominant form of sanitation used and owned by the IG and CG. The type of facilities used and the type owned by households were assessed, as respondents may prefer to defecate in the open or use other facilities if their household toilets are poorly maintained. No difference was observed between ownership and use within the study arms: in the IG, 346 (87.15%) reportedly owned and 348 (87.66%) used this type of latrine. A similar pattern of 57 (74%) of household ownership and use was also observed in the CG. Though no difference was observed in ownership and use *within* the study groups, a statistically significant difference was obtained *between* the IG and CG in both the possession of traditional pit latrines ($p < 0.003$; OR: 2.38; 95% CI; 1.27–4.45) and the use of traditional pit latrines ($p < 0.004$; OR: 2.49; 95% CI; 1.38–4.50). The IG was more likely to own and use traditional pit latrines (Table 3.9).

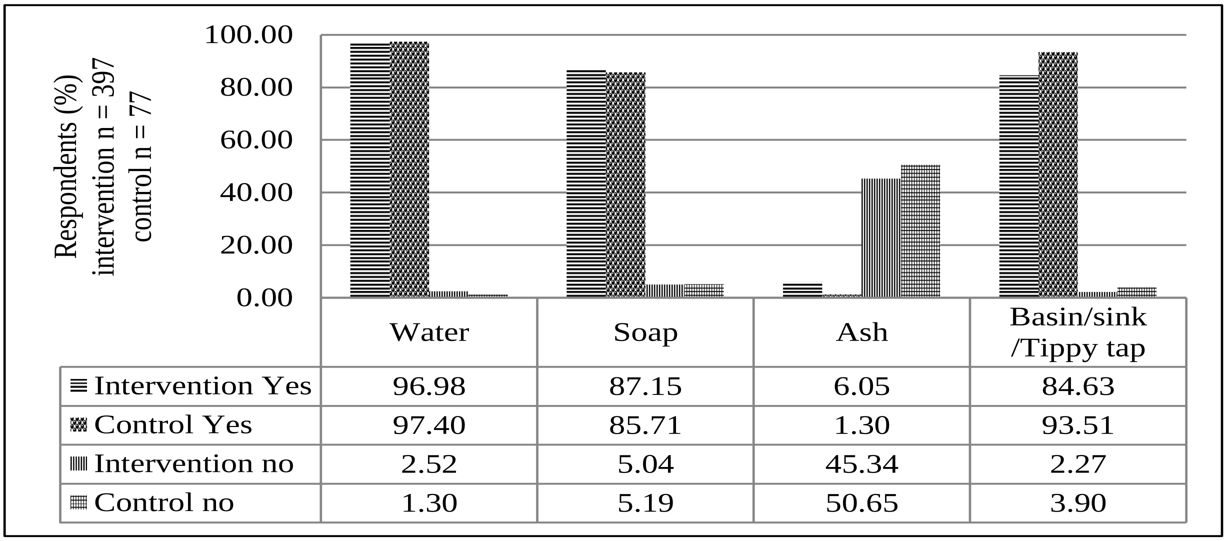
Table 3.9 Types of sanitation facilities available in households and used by households.

Sanitation facilities	Available in household				Used by households				Test of significance				Test of significance			
									Use				Available in household			
Variable	Intervention		Control		Intervention		Control		≠P	OR	95% CI		#P	OR	95% CI	
	n = 397		(n = 77		n = 397		n = 77									
N = 474	Freq	%	Freq	%	Freq	%	Freq	(%)								
Improved	39	9.82	7	9.91	36	9.06	6	6.78					0.848	1.09	0.47	2.53
Unimproved	354	89.17	69	89.62	359	90.43	71	92.21					1	1.05	0.47	2.33
No response	4	1.01	1	1.30	2	0.50	0	0								
No facility	8	2.02	11	14.29	10	2.53	14	18.18	*0.0001	0.12	0.05	0.27	*0.0002	0.12	0.04	0.35
Pit latrine with slab	32	8.06	2	2.6	29	7.34	2	2.6	0.089	3.29	0.75	20.29	0.204	2.96	0.7	12.65
Ventilated improved pit latrine	5	1.26	3	3.9	5	1.26	3	3.9	0.1	0.31	0.06	2.08	0.125	0.32	0.07	1.35
Traditional pit latrine	346	87.15	57	74.03	348	87.66	57	74.03	*0.003	2.38	1.27	4.45	*0.004	2.49	1.38	4.5
Flush to tank	0	0	0	0	0	0	1	1.3	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Pour flush	0	0	1	1.3	1	0.25	0	0	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Flush to unknown	2	0.5	1	1.3	1	0.25	0	0	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Composting toilet	0	0	1	1.3	0	0	0	0	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Hanging toilet	0	0	0	0	1	0.25	0	0	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
No response	4	1.01	1	1.30	2	0.50	0	0								
Total	397	100	77	100	397	100	77	100								

Fisher's exact test was used for cells with frequencies below 5; ≠ test of significance of the *use* of facilities between intervention and control; # test of significance of the *availability* of facilities between intervention and control; N/D: Not done because the cell frequencies were very small; Freq: Frequency; P: p value; OR: Odds ratio; CI: Confidence interval; *: statistical difference at $p \leq 0.05$

Hygiene

The interviewers’ observation of hygiene-related facilities indicated that a similar percentage of respondents in the two study arms owned a handwashing facility either in the form of a basin, tippy tap or sink: 336 (84.63%) in IG and 72 (93.51%) in CG. Water was observed in the handwashing facilities in similarly high proportions of households in both study arms: 385 (96.98%) in IG and 75 (97.40%) in CG. Soap was observed near the facility in 346 (87.15%) in IG and 66 (85.71%) in CG. Ash was also observed near the handwashing facilities (Figure 3.6).



	Water	Soap	Ash	Basin/sink /Tippy tap
≡ Intervention Yes	96.98	87.15	6.05	84.63
▩ Control Yes	97.40	85.71	1.30	93.51
▥ Intervention no	2.52	5.04	45.34	2.27
▦ Control no	1.30	5.19	50.65	3.90

Figure 3.6 Handwashing-related observations.

Sanitation-related knowledge, attitudes and practices

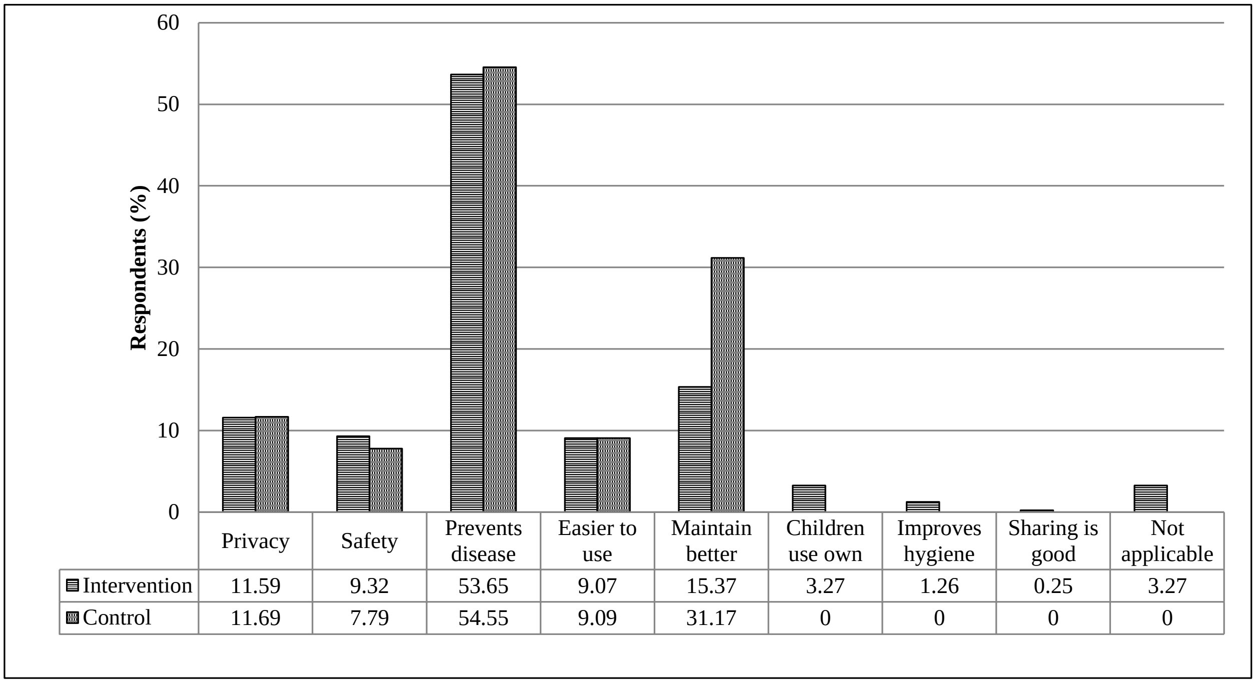
In the households studied, children under five years of age defecated around the house, in the potty, in the toilet, on the ground (Table 3.10). When the places were grouped into safe and unsafe defecation practices, about two of every five children defecated in unsafe places, with a similar proportion observed in the two study groups (Table 3.10). Generally, the IG had significantly higher odds of practicing safe child sanitation in comparison with the CG. The IG had a significantly higher likelihood than the CG of disposing of U5 faeces safely ($p < 0003$; OR: 5.76; 95% CI: 2.04–16.29) and also of disposing of anal cleansing materials safely ($p < 0.0001$; OR: 4.29**;** 95% CI: 2.00–9.18) (Table 3.10).

Table 3.10 Places of defecation and disposal of faeces of children aged below five and anal cleansing materials used by respondent.

Variable	Intervention		Control		Test of significance
	Frequency	%	Frequency	%	
*Places of U5 defecation n = 278					
Around the house	93	40.43	19	40.43	
In the potty/chamber pot	42	18.26	9	19.15	
In the toilet	57	24.78	13	27.66	
In napkin	30	13.04	6	12.77	
Unspecified others	8	3.48	0	0	
Total = 278	230	100	47	100	
Safe places of defecation	129	58.11	28	59.57	p = 0.85; OR: 0.94; 95% CI: 0.50–1.77
Unsafe places of defecation	93	41.89	38	82.61	
*Disposal of child faeces n = 277					
Dropped into toilet	199	86.9	31	64.58	
Eaten by dogs	1	0.44	1	2.08	
Buried in soil	20	8.73	7	14.58	
Thrown in bush	6	2.62	5	10.42	
Disposed with solid waste	1	0.44	1	2.08	
Do nothing specific	2	0.87	3	6.25	
Total = 277	229	100	48	100	
Safe places of faecal disposal	219	96.48	38	82.61	p<0.0003; OR: 5.76; 95% CI: 2.04–16.28
Unsafe places of faecal disposal	8	3.52	8	17.39	
Disposal of anal cleansing materials n = 474					
Store and burn later	8	2.02	1	1.30	
Throw inside bush	18	4.53	13	16.88	
Throw inside latrine	366	92.19	62	15.62	
Missing responses	5	1.26	1	1.30	
Total	397	100	77	100	
Safe places of cleansing material disposal	374	94.21	63	81.82	p< 0.0001; OR: 4.29; 95% CI: 2.00–9.18
Unsafe places of cleansing material disposal	18	4.53	13	16.88	

U5: child aged below 5 years; *the calculation of U5 defecation and faecal disposal practices is based on the number of households with children. OR: Odds ratio; CI: Confidence interval

Some of the results gave an insight into the attitude of the respondents towards sanitation. For example, the majority of the respondents in both study groups thought it was important to have toilets in their households: 326 (82.74%) and 70 (90.91%) in the IG and CG groups respectively. Over half the respondents in both study groups mentioned disease prevention as a motivator for toilet ownership by household and about a sixth of IG 61 (15.37%) and a third of the CG 24 (31.17%) mentioned better maintenance (Figure 3.7). Other reasons given included privacy which was mentioned by a little over 10% of both study groups, ease of use by about 9% in both study groups, and safety by about 9% and 7% in the IG and CG respectively. No respondent mentioned culture as a reason (Figure 3.7). There was no significant difference between the attitude of the study groups except that the IG were significantly more likely to mention better maintenance as the reason why households should own their own toilets ($p < 0.0009$; OR: 2.49; 95% CI: 1.43: 4.34).



	Privacy	Safety	Prevents disease	Easier to use	Maintain better	Children use own	Improves hygiene	Sharing is good	Not applicable
▤ Intervention	11.59	9.32	53.65	9.07	15.37	3.27	1.26	0.25	3.27
▦ Control	11.69	7.79	54.55	9.09	31.17	0	0	0	0

Figure 3.7 Reasons given by respondents for owning toilets; multiple responses given.

Personal, household and environmental hygiene-related knowledge, attitudes and practices

The respondents *appeared* to know about the relationship between handwashing and diarrhoea, with a high percentage noting that diarrhoea can be contracted by not washing hands with soap and water: 314 (79.09%) in the IG and 59 (76.62%) in the CG. Other diseases mentioned, in descending order are cholera 236 (59.45%) in IG and 33 (42.86%) in CG and typhoid 131 (33.00%) in IG and 36 (46.75%) in CG. A few respondents mentioned HIV/AIDS and yellow fever. There was no significant difference between the two groups in frequency of the diseases mentioned except for typhoid fever which the IG was significantly more likely to mention than the CG (Table 3.11).

Table 3.11 Respondents’ perceptions of diseases that can be contracted by adults if hands are not washed after defecation.

Variable	**Intervention (n = 397)**		**Control (n = 77)**		**Test of significance (Adult)**			
Diseases	Frequency	%	Frequency	%	p value	OR	95% CI	
Malaria	13	3.27	2	2.6	0.76	0.79	1.74	3.56
Tuberculosis	2	0.5	2	2.6	0.07	5.27	0.73	37.93
Typhoid	131	33	36	46.75	0.02	1.78	1.09	2.92
Yellow fever	1	0.25	0	0	0.66	N/A	N/A	N/A
Diarrhoea	314	79.09	59	76.62	0.63	0.87	0.49	1.55
Cholera	236	59.45	33	42.86	0.07	0.51	0.31	0.84
HIV/Aids	3	0.76	1	1.3	0.63	1.73	0.18	16.84
Don’t know	8	2.02	4	5.19	0.1	2.67	0.78	9.08

Multiple response question, percentage may not be equal to 100%; OR: Odds ratio; CI: Confidence interval; $p \leq 0.05$ denotes statistical significance.

The respondents’ knowledge *appeared* to tally with their reported use of soap, as most of the respondents in both study arms: 386 (97.23%) in IG and 76 (98.70%) in CG indicated that they had used soap in the previous 24 hours before the survey. The observations made by the interviewers confirmed the self-reported use of soap with a majority of both IG and CG having handwashing facilities with soap and water (as earlier shown in Figure 3.6).

Though these observations confirm that the households wash their hands with soap as they self-reported, the reported use of soap is a cause for concern when viewed in relation to safe drinking water-related practices. The soap was mainly used for bathing in the two study arms by 266 (66.75%) in IG and 52 (67.53%) in CG respectively, followed by laundry by a little less than half of the respondents in the two study arms: 175 (44.08%) in IG and 33 (42.86%) in CG (Table 3.12). Soap was used to wash hands after faecal contact by only about a third of the respondents in the IG and about one fifth (20.78%) of the CG, who reported that they used soap in the past day to wash their hands after defecation. Use of soap after child defecation-related activities such as cleaning the child’s bottom, washing the child’s hands or washing own hands after cleaning child were mentioned by less than 5% of respondents in both study arms. There was no statistical difference in uses of soap between the two study arms except for washing hands with soap before eating ($p < 0.04$; OR: 0.44; 95% CI: 0.19–0.99 (Table 3.12). The practices are at odds with a stated understanding that not washing hands with soap can cause diarrhoea.

Table 3.12 Use of soap by respondents the day before the study.

Variable	**Intervention(n =397)**		**Control (n = 77)**		**Test of significance**			
Use of soap in the previous day	Frequency	%	Frequency	%	p value	OR	95% CI	
Washed clothes	175	44.08	33	42.86	0.84	0.95	0.58	1.56
Took my bath	266	67	52	67.53	0.93	1.02	0.61	1.73
Bathed children	25	6.3	2	2.6	0.2	0.4	0.09	1.71
Wash child's bottom	11	2.77	3	3.9	0.59	1.42	0.39	5.22
Wash child's hands	7	1.76	0	0	0.24	N/A	N/A	N/A
Wash my hands after defecation	116	29.22	16	20.78	0.13	0.64	0.35	1.15
Wash my hands after cleaning my child	7	1.76	1	1.3	0.77	0.73	0.89	6.04
Wash hands before feeding child	23	5.79	4	5.19	0.84	0.89	0.3	2.65
Wash hands before preparing food	62	15.62	9	11.67	0.38	0.72	0.34	1.51
Wash hands before eating	74	18.64	7	9.09	0.04	0.44	0.19	0.99
Wash dishes	48	12.09	10	12.99	0.83	1.09	0.52	2.25

Multiple responses question, therefore percentage will not be 100%; OR: Odds ratio; CI: Confidence interval; $p \leq 0.05$ denotes statistical difference.

The results suggested that in the IG respondents' view, the three main critical times were in descending order, (91.18%, 87.41% and 78.34%) washing hands before eating, after defecating and after eating; this was also true in the CG's view. As was observed with the poor use of soap to wash hands after faecal contact, after defecation was mentioned as a critical time less frequently than before eating, while after urination was mentioned by only about 15% in both study groups (Table 3.13). Other child survival-related times such as breast feeding, before feeding child were mentioned by 20% or less in both study groups (Table 3.13).

Table 3.13 Respondents' perceptions of critical times to wash hands.

Variable	Intervention n = 397		Controls n = 77	
Critical times to wash hands	Frequency	%	Frequency	%
Before eating	362	91.18	75	97.40
After defecating	347	87.41	71	92.21
After eating	311	78.34	66	85.71
Before cooking	267	67.25	55	71.43
Before feeding child	79	19.90	10	12.99
Before breast feeding	74	18.64	12	15.58
After urinating	62	15.62	13	16.88
Before prayer	0	0.00	2	2.60

Multiple responses question, therefore percentage will not be 100%.

Water-related knowledge, attitudes and practices

Rainwater was used by most people with more than half of the respondents in both study arms using it frequently. Surface water was used almost as frequently as rainwater and almost half the respondents in both study arms indicated that it was their usual source of drinking water: 142 (47.81%) in IG and 24 (48.00%) in CG. These water sources were used for other purposes apart from drinking: cooking 379 (95.47%) in IG and 67 (87.01%) in CG; followed in descending order by washing utensils, washing hands, and bathing.

The importance of the distance to the source and accessibility of the water point as an indicator for safe drinking water supply is highlighted by the findings that the majority of respondents in the two study arms made between 1–4 trips a day to their main drinking water source: 273 (68.77%) and 60 (77.92%) in the IG and CG respectively. Most respondents took 30 minutes or less per trip, for example 274 (69.01%) in the IG and 45 (59.98%) in the CG. The range of trips was 1–15 per day and the time it took ranged from 30 minutes to over six hours.

The potential monetary value of the opportunity cost of fetching water for these households highlights the importance of improved water supplies in these communities, in which a third of both the IG and CG depend on surface water outside the rainy season.(Table 3.14). The potential economic value of the time spent fetching water by the study communities was calculated based on the following:

The time taken per trip is adapted from the following sources:

a) Cairncross and Valdamanis (2004) findings that studies in 23 African countries reported that more than 44% of the households took longer than 30 minutes per round trip to fetch water.

b) The WHO/UNICEF (2010) report that more than a quarter of households in African countries particularly in East Africa take longer than 30 minutes to collect water from their drinking water source i.e. per round trip and that a third of the improved water sources which are not piped take longer than 30 minutes to collect.

c) The dependence of the IG and CG on surface water sources.

d) The time cost per day was based on \$0.14/h, i.e. the average expenditure per hour in the 2nd poorest socio-economic quintile in Kenya (Ministry of Medical Services, 2009).

Table 3.14 Number of trips taken in a day to fetch water by respondents and monetary value of time taken.

Intervention					**Control**				
*No of trips/day/ respondent	%	*Time taken	*Time cost/day($)	Time cost/year($)	No of trips/day/ respondent	%	Time taken	Time cost/day ($)	Time cost/year ($)
0	0.51	0	0	0	0	0	0	0	0
1	6.68	30	0.07	25.55	1	20.55	30	0.07	25.55
2	13.88	60	0.14	51.10	2	9.59	60	0.14	51.10
3	28.28	90	0.21	76.65	3	34.25	90	0.21	76.65
4	21.34	120	0.28	102.20	4	17.81	120	0.28	102.20
5	8.48	150	0.35	127.75	5	4.11	150	0.35	127.75
6	9.25	180	0.42	153.30	6	5.48	180	0.42	153.30
7	5.14	210	0.49	178.85	7	2.74	210	0.49	178.85
8	2.31	240	0.70	255.50	8	4.11	240	0.70	255.50
9	0.77	270	0.63	229.95	9	0	270	0.63	229.95
10	2.57	300	0.70	255.50	10	0	N/A	N/A	N/A
11	0.26	330	0.77	281.05	11	0	N/A	N/A	N/A
12	0.26	360	0.84	306.60	12	1	1.37	N/A	N/A
15	0.26	390	0.91	332.15	15	0	N/A	N/A	N/A

*Time taken : 30 minutes/ trip adapted from Cairncross and Valdamanis (2004) and JMP 2010

* Time cost based on $0.14/hour as average household expenditure/hour in 2nd poorest socio-economic quintile in Kenya (Ministry of Medical Services, 2011).

*No of trips/day/respondent : KAP survey results

Table 3.14 shows that 50% of the population, who make 3–4 trips per day in the study communities, incur a potential opportunity cost of \$76.5–\$102/household/year, if it is assumed that the time spent fetching water would be spent on income-generating and other productive activities. Since the number of households in these communities range from 22–534, the opportunity cost ranges from \$1 683–54 574.8 per year (based on \$76.5/household/year). The cost of a 250 m deep borehole is 2 129 000 KES (about \$25 000 at the rate of 84 KES to \$1) (internal UNICEF Kenya document). The time cost of fetching water can be used to justify the provision of improved water sources which are situated less than 30 minutes away from the users.

Gender roles, respondents, reasons for selection of main drinking water source and functionality of water supply system

In both IG and CG households, water collection was mainly undertaken by female,; who spent more time than the males in fetching water. Figure 3.8 shows that in the IG, females that are 18 years and older were 18 times more responsible for fetching water than males in the same age group, while in the CG, females were three and a half times more responsible for this activity than the men of the same age group. Likewise, females between 15 and 18 years of age were twice more responsible for fetching water than young males of the same age category in both study groups (Figure 3.8).

The most frequently mentioned reason for selecting a main drinking water source in the two study arms was convenience 226 (56.93%) in IG and 45 (58.44%) in CG. Other less frequently mentioned reasons included the reliability of the supply 64 (16.12%) in IG and 8 (10.39%) in CG; clarity of the water 50 (12.59%) in IG and 13 (16.88%) in CG and safety for drinking /cooking 35 (8.82%) in IG and 7 (9.09%) in CG (Figure 3.9).

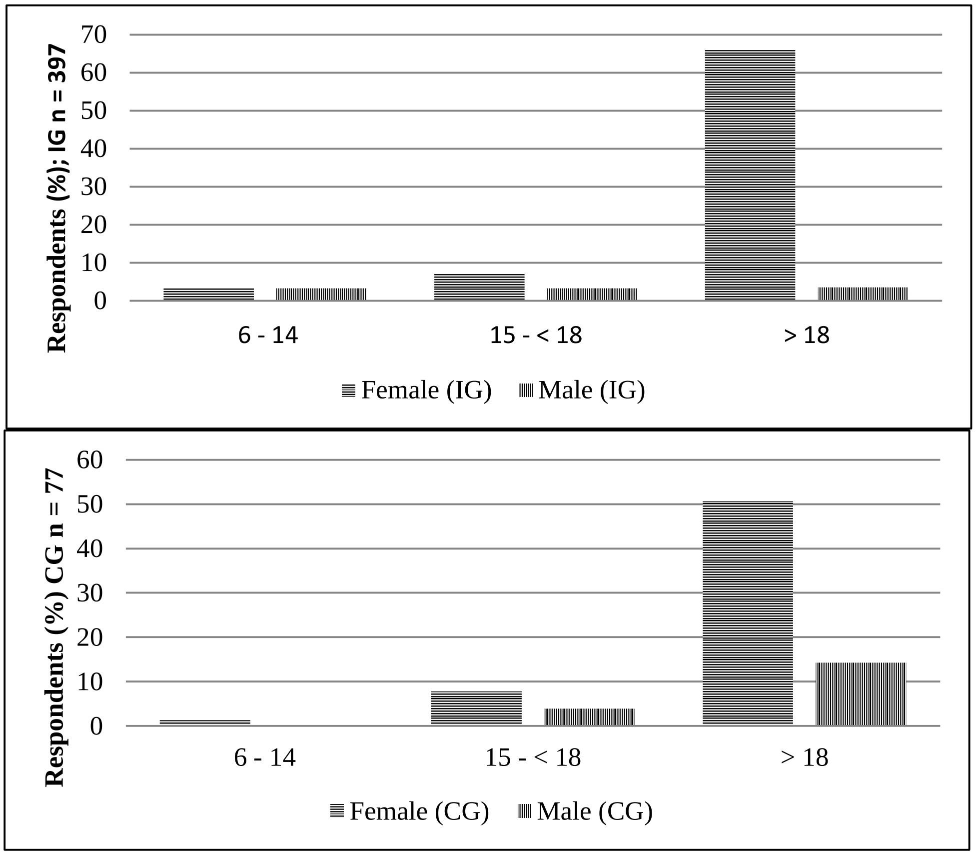
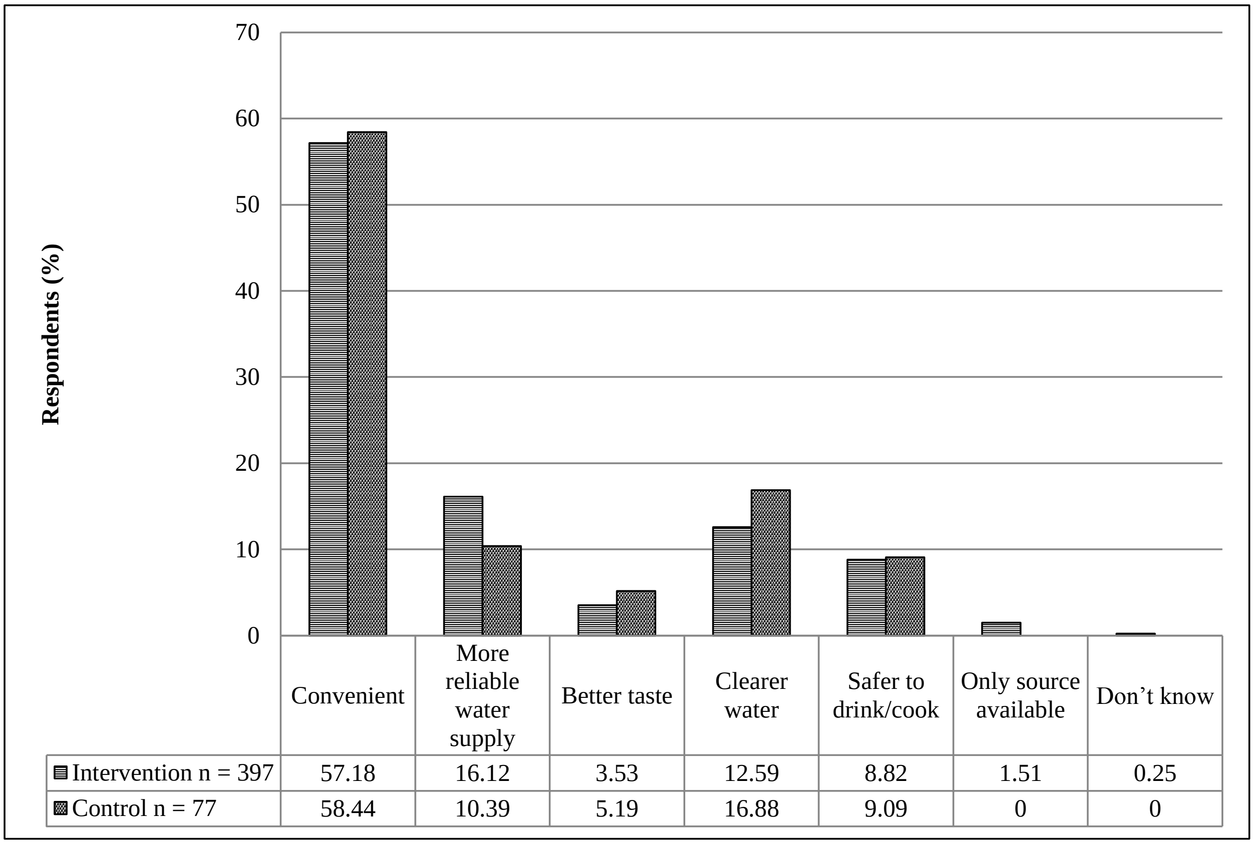


Figure 3.8 Person that fetches water in intervention and control households by gender and age group.

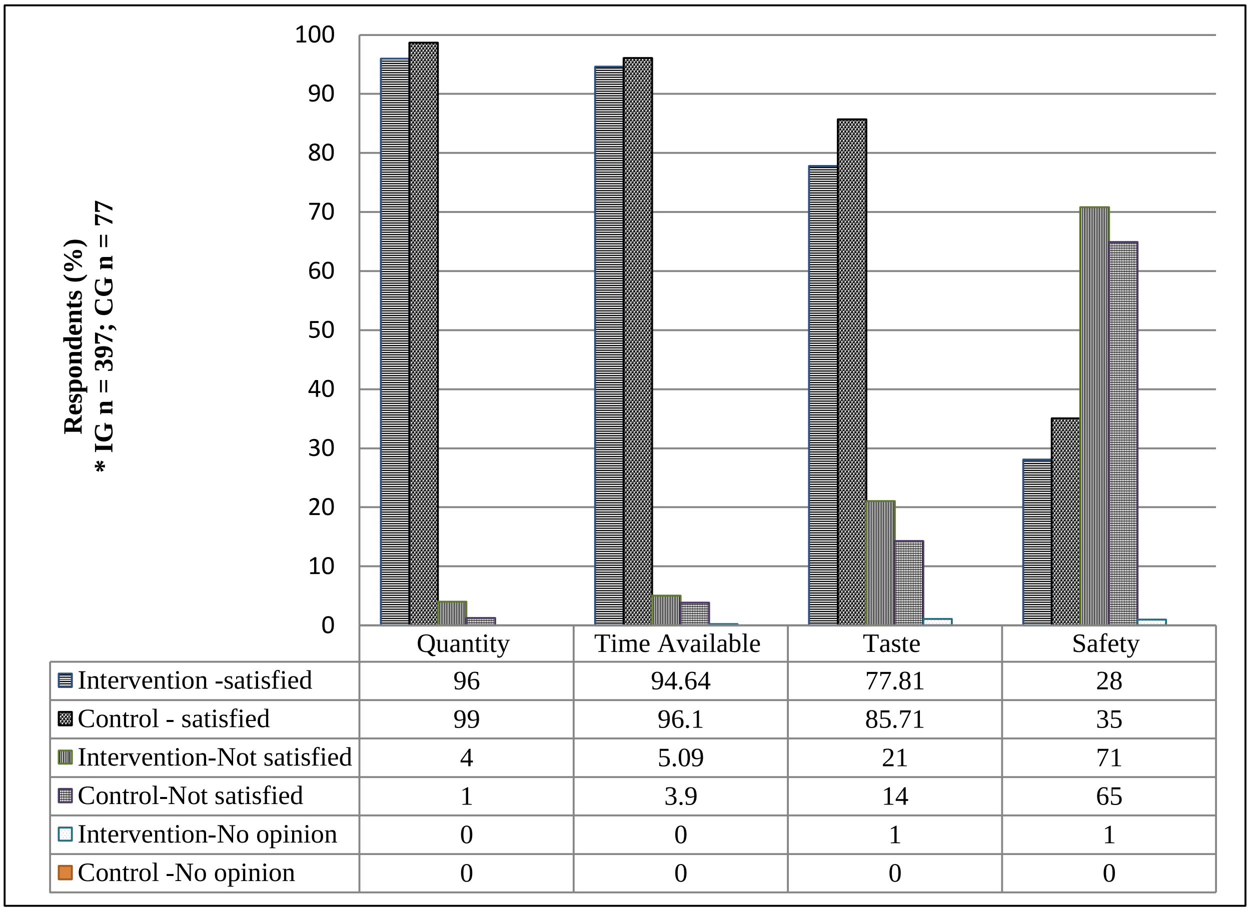
IG: intervention; n = 397; CG: control; n = 397. * 13.60% of intervention and 22.08% of control responses not shown because age was not specified and water was delivered by vendor.



	Convenient	More reliable water supply	Better taste	Clearer water	Safer to drink/cook	Only source available	Don't know
▤ Intervention n = 397	57.18	16.12	3.53	12.59	8.82	1.51	0.25
▩ Control n = 77	58.44	10.39	5.19	16.88	9.09	0	0

Figure 3.9 Respondents' reasons for selecting water source.

The quantity of water and the length of time it was available for use, are the two qualities most respondents (> 90%) found satisfactory about their drinking water in both study groups. A lower, but substantial percentage were satisfied with the taste of their main drinking water source 284 (77.81%) in the IG and 66 (85.71%) in the CG. Over two-thirds of both groups were dissatisfied with the safety of the water 277 (70.84%) in IG and 50 (64.94%) in CG (Figure 3.9).



	Quantity	Time Available	Taste	Safety
▤ Intervention -satisfied	96	94.64	77.81	28
▩ Control - satisfied	99	96.1	85.71	35
▥ Intervention-Not satisfied	4	5.09	21	71
▦ Control-Not satisfied	1	3.9	14	65
☐ Intervention-No opinion	0	0	1	1
■ Control -No opinion	0	0	0	0

Figure 3.10 The respondents' satisfaction with their main drinking water source.
IG: Intervention group; CG: Control group; n: sample size

Over 90% of respondents in the two study groups indicated that their water source had been available in the two weeks before the interview 385 (97.47%) in the IG and 74 (96.10%) in the CG. The remaining few that had been without water indicated that they had used alternative water sources.

Water quality and water treatment

Figure 3.11 indicates that both the IG and CG had the same expectations about drinking water quality. More than 80% of respondents from the two study groups mentioned visual clarity 349 (87.91 %) in the IG and 68 (88.31%) in the CG. This was followed by the absence of germs which was mentioned by more than 70% of respondents in both study arms 314 (79.09%) in the

IG and 56 (72.73%) in the CG. Taste was mentioned by about 10% and 15% of the IG and CG respectively. The difference between the expectations of the two groups was not statistically significant. The increased likelihood that user communities would seek aesthetically or better-tasting though more polluted water sources was observed in Tito, one of the intervention communities, where a functioning borehole was not used by the community, but they used an unprotected spring near the improved source (Figures 3.12 and 3.13).

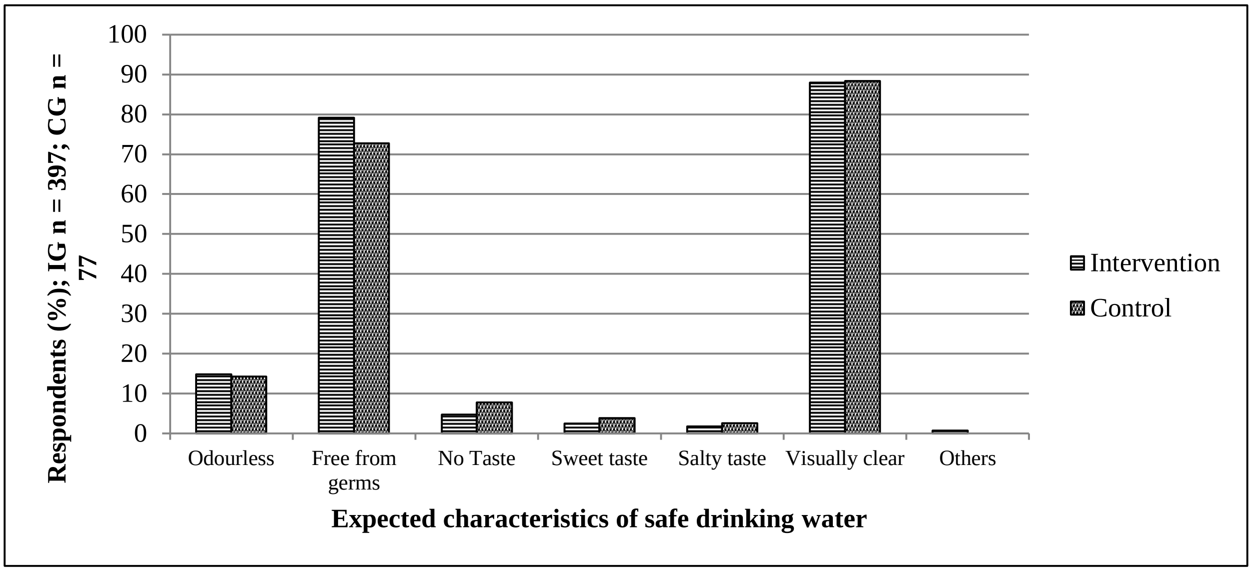


Figure 3.11 Respondents' expectations about the characteristics of safe drinking water. IG: Intervention group; CG: Control group; n: sample size

When asked what action they took when their drinking water quality did not meet their expectations for example in terms of visual clarity, about 20% of respondents in the IG and 40% in the CG took actions that were not related to water treatment. The results indicate that though the IG households were more aware of possible water treatment actions than the CG, there is a gap between water quality and knowledge of the most appropriate option to use (Table 3.15).

About the same number of respondents i.e. one third in both the intervention 125 (31.49%) and control group 25 (32.47%) indicated that there were times when they have drunk untreated water. The most frequent reason for not treating their water was the perceived safety of rainwater 42 (33.60%) in IG and 7 (28.00%) in CG. Cost was mentioned by 18% of the intervention group but by less than 5% of the control group (Appendix 3.6).

Figure 3.12 Abandoned improved source in Tito community.

Figure 3.13 Preferred unimproved source situated near the abandoned improved source

Table 3.15 Actions taken by respondents to improve visual clarity of water.

Action	Intervention		Control	
	Frequency	%	Frequency	%
Waterguard	78	38.81	13	41.94
PUR	26	12.94	2	6.45
Alum	18	8.96	2	6.45
Boiling	14	6.97	1	3.23
Ceramic filter	11	5.47	0	0.00
Aquatab	9	4.48	0	0.00
Cloth filter	4	1.99	1	3.23
Sand filter	2	1.00	0	0.00
No water treatment-related action	39	19.40	12	38.71
Total*	201	100	31	100

Knowledge about and attitudes towards diseases

Respondents mentioned diarrhoea, cholera and typhoid most frequently as the diseases that can be contracted when adults or children drink dirty water. However the answers indicated that the respondents believed that children were less susceptible to cholera and typhoid than to diarrhoea (Table 3.16). There was a statistically significant difference between the IG and CG in the mention of cholera as a water-borne disease in adults ($p < 0.04$; OR: 1.67; 95% CI: 1.01–2.75; Table 3.16).The IG mentioned cholera more frequently.

Most respondents could describe diarrhoea using words such as “loose”, “watery”, three or “more times than usual”. Only 12 (3.05%) in the IG did not know what diarrhoea was, while almost three times this percentage could not describe diarrhoea in the CG 6 (8.11%).

Despite the study group’s ability to describe diarrhoea and their earlier reported knowledge that not washing hands with soap may cause diarrhoea, both groups showed a disconnection between knowledge about *routes* of contamination and *barriers* to contamination. For example, less than one fifth of those that mentioned dirty food as a cause of diarrhoea mentioned washing fruits and vegetables as a barrier in the IG group (4:1) and an even smaller proportion (11:1) did so in the CG. Similarly, for every two people that mentioned dirty water as a source of contamination, only one person mentioned clean drinking water as a barrier. Likewise, only about half of those that mentioned dirty drinking water in the CG mentioned clean drinking water.

Table 3.16 Respondents’ perceptions about drinking water-related child and adult diseases.

Variable	**Intervention (n =397)**				**Control (n = 77)**				**p value**	**OR**	**95% CI**		**p value**	**OR**	**95% CI**	
Diseases from drinking dirty water	Adult		Child		Adult		Child		Test of significance (adult)				Test of significance (child)			
	Freq	%	Freq	%	Freq	%	Freq	%								
Malaria	25	6.30	28	7.05	8	10.39	6	7.79	0.20	0.58	0.25	1.34	0.82	0.90	0.36	2.48
Tuberculosis	3	0.76	2	0.50	0	0.00	0	0.00	0.44	N/A	N/A	N/A	0.53	N/A	N/A	N/A
Typhoid	209	52.64	187	47.10	41	53.25	34	44.16	0.92	0.98	0.60	1.60	0.64	1.13	0.69	1.84
Yellow fever	2	0.50	1	0.25	0	0.00	0	0.00	0.53	N/A	N/A	N/A	0.66	N/A	N/A	N/A
Diarrhoea	284	71.54	281	70.78	63	81.82	62	80.52	0.06	0.56	0.30	1.04	0.08	0.59	0.32	1.07
Cholera*	274	69.02	247	62.22	44	57.14	39	50.65	*0.04	1.67	1.01	2.75	0.06	1.60	0.98	2.62
HIV/AIDS	2	0.50	5	1.26	1	1.30	0	0.00	0.42	0.39	0.04	4.30	0.32	N/A	N/A	N/A

Freq; frequency; P: p value; OR: Odds ratio; CI: Confidence interval; *Significant difference observed at p ≤ 0.05; n: sample size

The proportion of those that mentioned dirty hands in comparison to washing hands was 2:1 in both study arms. The same disconnection was evident with sanitation. Significantly fewer people mentioned poor sanitation as a possible cause of diarrhoea, though a high percentage mentioned good sanitation as a barrier to diarrhoea in both groups i.e. 1:66 and 1:40 in IG and CG respectively. Figure 3.14 graphically shows the poor linkage between contamination routes and barriers.

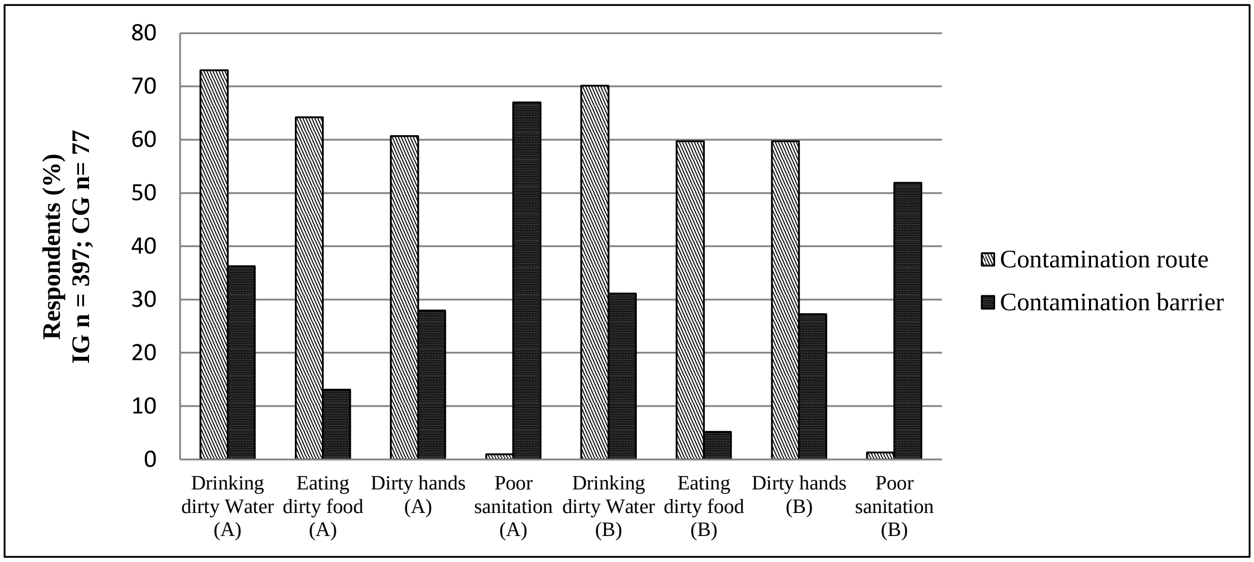


Figure 3.14 Respondent's gap in knowledge of contamination routes and barriers. A: intervention group; B: control group.

Just as the respondents did not link the causes of diarrhoea to its prevention, so the study results show that, in spite of their ability to describe diarrhoea, almost half the respondents in both study groups had a poor knowledge of the causes of diarrhoea and its prevention i.e. 208 (52.39%) and 45 (58.44%) in IG and CG respectively, with only 39 (9.82%) in the IG and 5 (6.49%) in the CG respectively having good knowledge. The remaining one-third fell into the "fair" knowledge category. There was no significant difference in knowledge about diarrhoea between the two groups.

When the respondents' knowledge was related to the reported incidence of diarrhoea in children under five years old, results revealed that the highest percentage of those that said their youngest child had an episode of diarrhoea during this period i.e. 34 (59.65%) in IG and 6 (75%) in CG, belonged to the category with the 'poor diarrhoea knowledge' (Table 3.17).

Table 3.17 Incidence of diarrhoea in the past two weeks before the study in children under five years in relation to diarrhoea knowledge of respondents.

	Yes				No			
Knowledge	Intervention		Control		Intervention		Control	
	n =57		n =8		n =312		n =57	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Good	0	0	0	0	38	12.18	5	8.77
Fair	23	40.35	2	25	119	38.14	21	36.84
Poor	34	59.65	6	75	155	49.68	31	54.39
Total	57	100	8	100	312	100	57	100

Good: 3 of 3; Fair: 2 of 3; Poor: 1 of 3

3.4.4 Factors which may affect water quality decline between source and point-of-use

According to Wright *et al*. (2004), the decline in bacterial quality of water after collection can be assessed in relation to the KAP-related characteristics of the settings. Table 3.18 shows some of such characteristics identified in this study. Statistical differences were observed between the IG and CG in some of these factors. For example, safe versus unsafe disposal of anal cleansing materials used by adults and the disposal of the faeces of children aged below five years. The relationship between these characteristics identified during the KAP survey and water quality deterioration will be examined statistically in Chapter Five.

Table 3.18 Characteristics identified during KAP survey that may lead to water quality deterioration.

Variable	**Intervention**		**Control**		**p value**	**OR**	**95% CI**
	Frequency	**%**	**Frequency**	**%**			
Use of soap in the past one day							
Yes	386	97.23	76	98.7	0.452	0.46	0.06-3.63
No	11	2.7	1	1.3			
Evidence of soap near handwashing facility	346	94.54	66	94.29	0.933	1.049	0.35–17
Evidence of HW facility	336	97.39	72	96	0.512	1.55	0.41–5.88
Importance of having household toilets							
Yes	326	82.74	70	90.91	0.073	0.48	0.19–1.14
No	68	17.26	7	9.09			
Sharing of household toilets							
Yes	138	34.94	34	47.89	0.034	0.58	0.34–0.99
No	253	64.05	36	50.7			
Safe versus unsafe U5 defecation practices	129	58.11	28	59.57	0.85	0.94	0.50–1.77
Safe versus U5 faeces disposal	219	96.48	38	82.61	0.0003	5.763	2.04–16.29
Safe versus unsafe anal cleansing material disposal	374	95.14	63	82.89	0.0001	4.29	2.00–9.18
No education of water treatment respondent	38	9.64	7	9.09	0.914		

U5: children aged below five years of age.

3.5 Discussion of findings on water, sanitation, and hygiene knowledge, attitudes and practices

The most pertinent result is the evidence that the knowledge, attitudes and practices of both study groups in relation to water, sanitation and hygiene, indicated that these are communities that may not benefit from the use of HWT technologies unless the contradictory KAP practices are addressed through an integrated health and hygiene and HWT promotion.

3.5.1 Matching of controls

The intervention and control households did not differ statistically in 18 of the 20 variables used to match them (Table 3.2). The two differences were that the intervention households were more likely than control households to have heard about their HWT method through a non-governmental organisation, and that household size was larger in the control groups. Thus other observed differences in their household water treatment-related knowledge, attitudes and practices can thus validly be attributed to the household water treatment promotion carried out in the intervention households. Furthermore, observed similarities between the two study groups may be used to generalise findings to other rural communities in Kenya.

The study observed that the intervention group (IG) had better sanitation practices than the control group (CG), perhaps because of the structured promotion of household water treatment in these communities. For example, though the two groups had similar improved and unimproved sanitation facilities in their households, the CG was less likely to have a facility and to use a traditional pit latrine, but more likely to practice open defecation (Table 3.9). Similarly, the CG was significantly less likely to practice safe adult and child sanitation than the IG (Table 3.10). Although Clasen *et al*. (2007b) noted that combined interventions do not improve the health benefits of household water treatment, Kvarnstrom *et al.* (2011) points out that the full health benefits of an environmental intervention can only be realised if excreta is contained hygienically by good sanitation practices. The differences in some sanitation practices between the two study groups highlights the importance of promoting HWT in an integrated manner by means of appropriately and designed user education.

3.5.2 Socio-economic and demographics of study households in relation to the effectiveness of household water treatment

The Joint Monitoring Programme (JMP) on water and sanitation notes that poverty predisposes a community to inadequate access to safe water and sanitation. This in turn predisposes a household to a need for effective HWT for disease prevention (Mintz *et al*., 2001). Globally, the richest quintile is more than twice as likely as the poorest quintile to use improved drinking water, and the poorest quintile, 16 times as likely to practice open defecation (WHO/UNICEF, 2010). Some of the poverty indices identified by the World Bank's (2003) Kenyan welfare monitoring survey indicated that both the IG and CG were poor (Table 3.3). The average household size observed in this study (6.06±2.83 IG and 4.86±2.30 CG) is closer to the survey's mean household size of 6.4 for the rural poor than the 3.3 mean household size for the non-poor. Similarly, since the European Commission (EC) (2001) noted that subsistence farming is an occupation of the poorest and most vulnerable in Kenya, the predominance of subsistence farming as the main occupation of the IG and CG and the low ownership of household assets by over 95% of both study groups place them in the poor category (Table 3.3).

Such poverty predisposes the communities to the inadequate access to water and sanitation which was observed in the two study groups. Just one in ten of the IG households had improved sanitation facilities and also used them, while just one in ten of the CG households had sanitation facilities and only one in twelve of the CG households used the facilities (Table 3.9). Various studies have also reported inadequate access to sanitation: 1 in 3 households use improved sanitation in rural Kenya (WHO/UNICEF, 2010); 1 in 2 households in Peru (Galiani and Orsola-Vidal's, 2010); 3 in 10 in India (Banda *et al.,* 2007) and 1 in 10 in Northern Nigeria (Onabolu *et al.,* 2011).

In conformity with what the poverty indices suggested, this study found that only about 1 in 2 of the households used improved water sources, which conforms to the 52% reported by WHO/UNICEF (2010) highlighting the need for household water treatment. Mintz *et al.,* (2001) also noted that because there is usually no functioning centralised treatment system in poor communities that have inadequate access to safe water, residents are left with no choice but to resort to treating their water at the household level to protect themselves from water-borne diseases.

3.5.3 Practices of study communities and effective household water treatment

However, the same indices of poverty which predispose the poor communities to a higher likelihood of inadequate access to safe water and sanitation and the need for HWT, also increased the likelihood that they will not have the necessary knowledge, attitudes and practices for effective household water treatment. McLaughlin *et al.* (2009) describes effective household water treatment as one that can improve water quality till the point-of-use within a real-world context where human behaviour combines with the proven efficacy of the HWT technology in the laboratory or during controlled studies.

Tumwine (2005) observed that communities significantly affected by diarrhoeal diseases, usually lack the ability and resources to maintain the quality of source-treated water. The income levels of rural communities have been directly related to unhygienic practices by Galiani and Orsola-Vidal (2010) who found that the lower the income level, the further the distance of the handwashing facilities from the houses and the higher the *E. coli* count in the samples taken from water used by the study participants to rinse hands. This is consistent with some of the observed practices of the predominantly poor IG and CG in this study. Table 3.9 shows that 2.53% of the IG practiced open defecation, similar to the 5.2% observed by Onabolu *et al*. (2011) in northern Nigeria, and that 20% of the CG practiced open defecation, similar to the 20% noted by Galiani and Orsola-Vidal (2010) in Peru. This highlights the need not just for household water treatment, but HWT promotion which has integrated hygienic practices with the appropriate use of HWT technologies.

The use of soap in both study arms to wash the child or respondent's hands after cleaning the child's bottom by less than 5% of respondents (Table 3.12), is similar to the findings of Galiani and Orsola-Vidal (2010) in a study in Peru, that less than half the caregivers who had reported washing their hands with soap the previous day had done so after faecal contact. Like the findings about the poor sanitation practices in both study groups, the poor use of soap after faecal contact will reduce the likelihood of effective HWT, especially with those technologies that do not leave a residual effect such as ceramic filters. In a trial of ceramic filters in Cambodia, Brown *et al.* (2007) observed that only 40% of the samples of water treated with ceramic filters were below 1 cfu/100 ml, which is not surprising as only 35% of the respondents indicated that they washed their hands with soap and water after defecating.

The predominant use of unimproved water sources (predominantly surface water), by almost half of the IG and CG in the non-rainy season (Table 3.8) also suggests a reduced likelihood of effective household water treatment by these study communities and others like them. This conforms to the report by WHO/UNICEF (2010) that about 48% of people in rural Kenya use unimproved water sources, which is mostly surface water, (Younes and Bartram, 2001), and that less than 3% of drinking water sources in rural Kenya are boreholes, wells or protected springs (Albert *et al.*, 2010). This dependence on surface water increases the cost of treatment, due to high levels of contamination (Younes and Bartram, 2001) as well as reducing disinfection efficiency especially where the HWT method is hypochlorite-based (Sobsey *et al.*, 2008). Though these implications make it even more critical for such water sources to be treated effectively, they reduce the likelihood that these study communities and others will be able to use the HWT technologies optimally within a real-world context.

This claim is based on two premises. The first is that Sobsey *et al*. (2008) and WHO (2008) describe the optimal performance of HWT technologies in terms of the log reduction in microbes, which is achieved when operators are skilled and treat water of stable quality with adequate support. Secondly, some studies have shown that even better-educated operators of small water treatment plants apply incorrect doses of chlorine: for example in a study of 55 water treatment plants in South Africa, Obi *et al.* (2008) found that 51% and 73% of the finished water and point-of-use water samples did not comply with the water quality guidelines because of incorrect dosage of chlorine. These findings agree with those of McLaughlin *et al.* (2009), who in a study in Ecuador, found that even though laboratory tests showed significant log reductions in indicator organisms after chlorination, there was no significant difference between households that chlorinated their water because of inadequate chlorine dosing and improper storage conforms to this study’s results.

3.5.4 Knowledge of study communities and effective household water treatment

Given that the knowledge of the perceived benefits of a HWT technology and how to use it influences a household’s adoption of and compliance with HWT (Kraemer and Mosler, 2010), the low level of education observed in both IG and CG communities will negatively affect their ability to use HWT. The study found gaps in their knowledge about the relationship between contact with faeces and urine and diarrhoeal disease, such as the poor reported practice of hand washing with soap after contact with faeces or before feeding children (Table 3.13). This is similar to the findings by Galiani and Orsola-Vidal (2010) in Peru that when cooking or preparing food, caregivers washed their hands about two times more frequently than when feeding a child. In addition to a poor understanding of the critical times to wash hands, respondents in both the IG and CG were unable to link routes of contamination with their appropriate barriers (Figure 3.14), with only 1 in 2 of the respondents in both study groups mentioning handwashing as a means of preventing diarrhoea. Similarly the respondents in both study groups had a poor knowledge about the causes and prevention of diarrhoea with less than 10% of the respondents having good knowledge. Though Banda *et al.* (2007) also found that respondents in an Indian study did not attribute diarrhoea to unsafe water but attributed the disease to heat, mud or mosquitoes, the poor knowledge about diarrhoea and its connection with poor water quality predisposes such communities to a cycle of poor hygiene practices, and the recontamination of safe water sources (Tumwine, 2005) even after the water has been treated. Though not previously related to the effectiveness of household water treatment, the impact of knowledge on HWT is not surprising: Meierhofer and Landolt (2009) noted that once initial doubts are dispelled with the evidence of the efficacy of HWT (SODIS), people with a higher level of education and socio-economic status are more likely to adopt and sustain SODIS over a longer period.

3.5.5 Attitudes of households and their effect on the effectiveness of household water treatment

Attitudes of user households are critical in the evaluation of effective household water treatment because they influence the likelihood and consistency of households using the technology. An attitude that affects the effectiveness of household water treatment is that there is no need to treat the water or carry out the activities that will protect the water quality because the source water quality is good (Wright *et al.*, 2004). The perceived safety of rainwater was the most frequent reason given by 33.6% of those who had not treated water in the previous two weeks in the IG and 28% in the CG (Appendix 3.6), for not doing so. Brown *et al.* (2007) also observed that some of the users of ceramic filters in Cambodia discontinued their use because they felt that water did not need treatment to be safe. Though attitudes of study communities towards water and sanitation have previously been identified, this study's identification of attitudes that affect effective water treatment makes an important contribution to public health and provides a basis for the development of promotional material targeted at these attitudes as a strategy for improving the effectiveness of HWT technologies.

Both study communities considered water collection as a female responsibility with females spending a disproportionate amount of time compared to males fetching water, in two of the three age groups assessed (Figure 3.8). This is consistent with the WHO/UNICEF (2010) report covering 45 developing countries, that the collection of water was a female responsibility in two thirds of the households surveyed. This has far-reaching implications for household water treatment and beyond. The attainment of the various poverty-related Millennium Development Goals will for example, be negatively affected by the time lost by females in comparison with males, further widening the gender gap and impacting negatively on female education, maternal health, employment, income-generating opportunities and women empowerment (Editorial, 2010). In a study in rural Zimbabwe, Mehretu and Mutambirwa (1992) showed that the time spent on routine household activities by women is more than half the time available to them during the day. Therefore, the addition of the burden of HWT to the other household duties such as fetching water means that already over-burdened women have insufficient time to comply with the critical steps for effective household water treatment.

Though this study did not assess the mode of transport to the water sources or the distance to the water sources, the use of primary data collected and secondary data such as time taken per trip (WHO/UNICEF, 2010), and the possibility of spending \$0.14/h in rural Kenya (Ministry of Medical Services, 2011) are a valid representation in monetary terms of the opportunity costs to the study communities of fetching water.

This study found that the potential monetary value of the time spent fetching water by 50% of the population who make 3–4 trips per day, was \$76.5-102.2/household/year (Table 3.14). This is disconcerting when considered within the context of the gender-skewed responsibilities in water collection to the detriment of women as observed in this and other studies

(WHO/UNICEF, 2010 and Mehretu and Mutambirwa, 1992); the significant energy costs incurred by the women with implications for the overall welfare of their households (Mehretu and Mutambirwa, 1992), and that the employed of IG (91.94%) and CG (85.71%) are predominantly subsistence farmers, which the EC (2001) describes as an occupation of the poorest and most vulnerable. The value of the opportunity costs gives an indication of the potential earnings of the water collectors who are predominantly female, assuming that they were employed in jobs that pay 14 cents per hour, as well as the monetary value of the time spent fetching water instead of on more productive activities such as education and skills development.

Improved water supply can reduce these opportunity costs, for example there is a 300% reduction or a cost difference of $51.10/household/year if a household makes one trip instead of three per day (Table 3.14). The translation of the opportunity costs of fetching water into monetary terms allows a comparison of the costs of providing a borehole or other improved water source with the opportunity costs of more distant sources that require more trips. The comparisons can then be used to justify the provision of more improved water sources closer to households (Cairncross and Valdamanis, 2004), particularly in the light of Wang and Hunter’s (2010) review of studies carried out in Tanzania, Zaire, Nicaragua, Bangladesh and Uzbekistan that increased distance to a water source may increase the risk of childhood diarrhoea, and Mehretu and Mutambirwa’s (1992) emphasis on the energy costs to women of multiple trips.

3.6 Conclusion

Communities such as the IG and CG of this study are disproportionately disadvantaged in terms of water and sanitation access by virtue of their socio-economic indices, which in turn predispose them to knowledge, attitudes and practices which have the potential to reduce the effectiveness of HWT methods. Their socio-economic indices also place them in the category of HWT operators who are unlikely to use the HWT technologies optimally. Though KAP studies have previously been conducted, this study’s use of a quasi-experimental design to conduct a KAP study provides the sector with previously unavailable information about those KAP which need to be addressed in HWT promotion to ensure effective household water treatment in a real-world context. Furthermore, the presence of these characteristics in both study groups also forms a basis for the generalisation of these findings to other rural African communities.

4 LIKELIHOOD OF THE ADOPTION OF AND COMPLIANCE WITH HOUSEHOLD WATER TREATMENT TECHNOLOGIES BASED ON THEIR PERCEIVED VALUE

4.1 Introduction

The findings of the knowledge, attitudes and practices (KAP) survey presented in Chapter Three highlight the importance of household water treatment (HWT) in the study communities. HWT is necessary because these communities have inadequate access to improved water sources; rely on rainwater in a setting of poor sanitation and have inadequate knowledge of the causes and prevention of water and sanitation-related diseases. Rosa *et al.* (2010) noted however that in spite of the fact that rural African households are at the greatest risk of water-borne diseases, they are the least likely to adopt HWT technologies. This chapter assesses the value placed on HWT technologies by study households and the likelihood of adoption and compliance, which are behavioural factors that may affect HWT effectiveness.

The drinking water supply sector can gain an increased understanding of why water interventions fail or succeed by examining four principal issues (deWilde *et al.*, 2008). They are: drinking water as the main route of exposure to enteric pathogens; the correct use of the intervention; the consistent consumption of the water provided by the intervention, and the practice of water quality maintenance till the point-of-use (deWilde *et al.*, 2008).

These four issues affect the ability of an intervention to maintain microbial quality till it is consumed by the user, thereby reducing diarrhoeal infections (deWilde *et al.*, 2008). These issues are governed by technical, financial and social behavioural factors, which in turn affect the adoption of and compliance with HWT. Several authors have proffered suggestions about how these factors influence the adoption of HWT, and social marketing programs have been designed around these behavioural determinants (Table 4.1) (deWilde *et al.*, 2008; Luby *et al.*, 2008; Meierhofer and Landolt, 2008; Stevenson, 2008; Holla and Kremer, 2009; Kraemer and Mosler, 2010). Some of the social factors which affect adoption are peer involvement in the promotion of HWT (Meierhofer and Landolt, 2008; Holla and Kremer, 2009), social influence gained by the knowledge of other people using a particular technology (Meierhofer and Landolt, 2008;

Kraemer and Mosler, 2010), and a positive attitude towards the technology (Kraemer and Mosler, 2010). Other social factors are the educational level of the users (Meierhofer and Landolt, 2008), the perceived ability to use the technology and positive beliefs about the time taken to use the technology (Kraemer and Mosler, 2010), positive beliefs about the cost of the HWT and the perception that the benefits outweigh the cost (Kraemer and Mosler, 2010).

The technical factors related to HWT adoption are local availability of the equipment (Meierhofer and Landolt, 2008; Sobsey *et al*., 2008); the product design in terms of time taken to treat water, ease of use, and quantity of water produced (Sobsey *et al*., 2008); and knowledge about why an HWT technology should be used (Kraemer and Mosler, 2010).

Examples of financial factors include the price of the product and the presence or absence of subsidies in the sale of the products (Holla and Kremer, 2009). Wood *et al*. (2011) noted however, that social marketing has succeeded in increasing brand awareness, rather than the rates of HWT adoption.

Table 4.1 The technical, social and financial behavioural factors influencing the adoption of and compliance with household water treatment technologies (deWilde *et al.*, 2008; Luby *et al*., 2008; Meierhofer and Landolt, 2008; Stevenson, 2008; Holla and Kremer, 2009; Kraemer and Mosler, 2010).

Stage	Technical	Financial	Social	Setting
Adoption	Efficacy of system	Cost of HWT	Positive beliefs about time taken	Water and sanitation level in community
	Effective use of the system	Presence or absence of subsidy	Positive perception about costs of HWT	Socio-economic status
	Access to system	Socio-economic status	Positive attitude towards HWT	Quality of available water
	Functionality of system		Perceived technical knowledge and ability to use system	
	Product design		Perception that benefits outweigh costs	
	Knowledge about why HWT should be used		Adopter style of household head	
	Provision of training for technology		Social influence of technology	
	Training methods		Household priorities	
	Promotional strategies used		Peer involvement in	
	Distribution mechanism			
Compliance				
	Correct use	Product design (cost)	Consistent treatment	Water and sanitation level in the community
	Product design (number of steps in process, ease of use, time taken and quantity produced)		Consistent consumption of treated water	Socio-economic status
				Quality of available water

Ashraf *et al*. (2007) observed an inverse relationship between price of an HWT technology and its take-up but did not observe a statistically significant relationship between price and use. Wood *et al*. (2011) observed that HWT adoption does not necessarily translate into consistent use, a view Sobsey *et al*. (2008) concur with, observing that studies have not shown evidence of long-term sustained use of SODIS and hypochlorite-based POU technologies. For example, although Waterguard was the cheapest amongst a range of HWT options, it was the least likely to be used (Sobsey *et al*., 2008). It has been suggested that HWT compliance is dependent on some social factors which include the habitual and consistent treatment of water (Sobsey *et al.,* 2008; Kraemer and Mosler, 2010); the effective use of HWT (Luby *et al.,* 2008), and the consistent consumption of treated water by all household members (Sobsey *et al.,* 2008).

Wood *et al*. (2011) attributes the gap between awareness of a product and its adoption, and between adoption of a product and its consistent use, to a poor understanding of the perceived value placed on a product by the user. They point out that perceived value extends beyond the economic cost of the HWT.

Determining user adoption of and compliance with HWT must be carried out with an awareness of the setting, for example, in relation to the households' storage patterns, because contamination may occur at source or during storage (Mintz *et al.,* 1995; Tumwine, 2005). Households often collect water from unimproved contaminated sources or from uncontaminated non-piped sources and store it in containers that are open to contamination (Mintz *et al.*, 1995). Piped supplies may also become re-contaminated as a result of poor storage and unsanitary collection (Sobsey *et al*., 2008).

The mouth type of the drinking water storage container and how water is collected from it also affects recontamination. Wide-mouthed storage vessels are vulnerable to contamination from hands and cups dipped into them. Other factors that may contribute to the deterioration of water quality are the material of the storage container, whether the storage vessels are left uncovered, and whether a different container is used for collection and storage (Wright *et al.*, 2004). Storage alone cannot improve water quality if it is already contaminated at source but a safe storage vessel can maintain microbiological water quality after treatment (Mintz *et al.*, 1995).

The Pan American Organisation and the Centre for Disease Control proposed some characteristics for a safe storage vessel (Table 4.2).

Table 4.2 Characteristics of safe water storage as proposed by PAO and CDC (Mintz *et al.*, 1995).

Vessels should

1. be constructed of translucent high-density polyethylene plastic or similar material that is durable, lightweight, non-oxidizing, easy to clean, inexpensive, and able to be locally produced;
2. hold an appropriate standard volume (e.g. 20 l), have a stable base and a sturdy, comfortable handle for easy carrying;
3. have a single opening 5 to 8 cm in diameter with a strong, tightly fitting cover that makes it easy to fill the container and add disinfectant but difficult to immerse hands or utensils;
4. have a non-rusting, durable, cleanable spigot for extracting water;
5. allow air to enter as water is extracted and
6. have volume indicators and illustrations of safe water handling practices displayed on the outside of the vessel.

The use of such vessels has been observed to reduce the geometric mean of faecal coliforms by 69% and the incidence of diarrhoeal diseases in children under 5 years of age by 31% in a study carried out in Malawi (Roberts *et al.*, 2001). However, in spite of the promotion of safe storage, Levy *et al*. (2008) observed that about a third the drinking water sources they traced from source to the point-of-use became re-contaminated, thus buttressing the view of Waddington *et al*. (2009) that there is a dearth of information about why some water supply interventions are effective and others are not.

The study therefore investigated the perceived value attached to selected HWT technologies by the intervention and control communities, using behavioural determinants (aspects of the technology, which affect behaviour) related to adoption. Furthermore, because adoption of an HWT technology does not mean it is consistently used (Wood *et al.*, 2011), this study used the behavioural determinants related to compliance to also examine the perceived value of HWT technologies and to rank them. The findings are expected to provide reasons for the observed level of HWT effectiveness, information for reviewing HWT technology designs and programs and scaling up HWT adoption and compliance in these communities. Tables 4.3 and 4.4 summatively show the use of the behavioural indicators to develop a likelihood of adoption and compliance scale.

Table 4.3 Adoption and compliance indicators for assessing perceived value of HWT methods.

Adoption indicators	**Compliance indicators**		
1. Perceptions about HWT method	2. Sustained use	3. Correct use of HWT method	4. Characteristics users like about HWT method
(a) Perceived effectiveness of water treatment in relation to killing germs	(a) Number of current self-reported users of method	(a) Knowledge of critical steps for each water treatment method	(a) Efficacy of method
(b) Perceived effectiveness of water treatment in relation to diarrhoea prevention	(b) Interviewer sighting of products for method		(b) Ease of accessing HWT material
(d) Perceived cost of water treatment method	(c) Number of households that treated water in the week before the study		(c) Affordability
(d) Whether benefits outweigh costs	(d) Number of times respondent had forgotten to treat water in the previous month		(d)Time taken to use
(e) Perceived ability to use the method			
(f) Ease of accessing water treatment materials			
(g) Time taken to treat			
(h) Likelihood of using the method in the following two weeks			
(i) Whether water treatment is good or bad			
(j) Use by family and friends			
Maximum points = 10 * 10 =100	Maximum points possible = 10* 4 = 40	Maximum points possible= 10*1 = 10	Maximum points possible = 10* 4 = 40

HWT: Household water treatment

Table 4.4 Development of scale for the likelihood of adoption and compliance (Adapted from Davidson *et al.*, 2002).

Respondents' responses (%)	**Points**	**Total points as percentage (%)**	**Perceived value**	**Likelihood of adoption and compliance**
91–100	10			
81–90	9	81–100	Very high	Almost certain or highly likely
71–80	8	61–80	High	Likely
61–70	7	41–60	Fairly high	Moderate or fairly likely
51–60	6	21–40	Low	Unlikely
41–50	5	0–20	Very low	Rare or highly unlikely
31–40	4			
21–30	3			
11–20	2			
0–10	1			

4.2 Methods

4.2.1 Study area

The study area is the same as that of the KAP survey and has been reported in Chapter Two, Section 2.2

4.2.2 Sampling method and sample size

Refer to Section 2.4.1

4.2.3 Data collection

A survey was carried out to examine the respondents' perceptions about HWT technologies. Trained interviewers administered semi-structured questionnaires in the 474 KAP households during the rainy season from March to May 2010 (Appendix 4.1). Unlike the KAP survey, which had the primary care giver as the respondent, the respondent for the HWT adoption survey was the person responsible for keeping drinking water clean, irrespective of gender, or whether the household treated water or not.

The questionnaire was structured into three assessment categories each having specific indicators; (a) the general overview, (b) adoption and (c) compliance (Table 4.3). The general overview questions assessed the gender of the respondents and their household heads and the respondents' KAP practices in relation to water treatment, storage and water consumption. The adoption questions were selected from the factors identified in Table 4.1 and were addressed to all the respondents in respect of all the HWT technologies they had heard of, though they may not have used them. The compliance questions were also extracted from Table 4.1 but addressed to all the respondents according to the HWT technologies they currently used as their main drinking water treatment method. The IG had heard of eleven methods and the CG had heard of eight, these were examined in relation to the methods that had been promoted in the IG by SWAP and KWAHO and traditional methods. The promoted methods were SODIS, Aquatab, Waterguard, PUR and ceramic filters. The traditional methods are boiling, alum, and filtration with cloth. Perceptions about ceramic filters, Waterguard, Aquatab, PUR and boiling were examined amongst the users in the IG and CG, with the exception of ceramic filters which no CG household had heard of or used at the time of the study.

The questionnaire was validated by asking the respondent to show the interviewer the household's water storage containers and the water product they had self-reported as their main treatment method. Chlorine residual tests in the households that self-reported the use of hypochlorite-based methods were also used to assess whether the household used these products.

4.2.4 Data analysis

Step A General overview

Refer to Section 2.7

Step B Adoption

1. Indicators of perceived value: respondents' perceptions about ten aspects of HWT methods (Table 4.3).
2. Points assigned to each HWT technology on a scale of 1–10 based on the frequencies of responses.
3. Total score calculated for each HWT method
4. Total percentage calculated according to total points scored/maximum possible score.

Step C Compliance

1. Indicators of perceived value were categorised as sustained use, correct use and users likes (Table 4.3).
2. Steps 2, 3 and 4 above

Correct use, was assessed by asking the respondents to explain three steps that were important for ensuring that their current household water treatment method was effective. A score of 1 was given for every correct answer and the score obtained was used to categorize respondents into conversant and non-conversant: a score of 3 out 3 points = conversant and < 3 out of 3 points = non conversant. The percentage of conversant users was used to assign points to each HWT method and the process followed for adoption was used to calculate the total points and total percentage for each HWT method.

Free chlorine residual levels of stored water samples in 152 of the households using chlorine-based HWT technologies were assessed, by taking three replicate samples and the average value for each household determined. The average free chlorine levels were categorized into 0.1–< 0.2 mg/l = inadequate; 0.2–< 2 mg/l = adequate and above 2 mg/l–< 5 mg/l = super chlorination; > 5 mg/l = excessive.

Step D Calculation of perceived value

1. Sum up the grand total of the points for each HWT method in the adoption and compliance categories.
2. Calculate the percentage for each HWT method using the total points scored for adoption and compliance (Table 4.3).

Step E Interpretation of perceived value on a likelihood of adoption and compliance scale

1. Interpret the perceived value derived in steps A–D on a likelihood of adoption and compliance scale (Table 4.4).

4.3 Results

4.3.1 General overview

Gender roles in HWT

Women had a greater responsibility than men for ensuring that the household drinking water was clean, in a proportion of 43:1 in intervention group (IG) and 7:1 in the control group (CG) with a statistically significant difference in female: male ratios ($p < 0.0001$; OR: 5.706; 95% CI: 2.19–14.89).

Knowledge, attitudes and practices: household water treatment

When asked what qualities they used to judge water as safe, visual clarity was foremost in both IG 338 (85.14%) and CG 72 (93.51%), followed by absence of germs IG 313 (78.44%) and CG 61 (79.27%.). Absence of an odour was a distant third expectation of both IG 13% and CG 16% (Appendix 4.2). The IG had heard about 11 HWT methods to improve their water quality and the CG eight (Appendix 4.3). Most of the households in the two study arms self-reported that they treated water IG 397 (95.71%) and CG 62 (80.52%). The main method used in both study groups was Waterguard which was used by 277 (69.95%) IG and 53 (68.83%) CG. In general, the use of all the other methods was low in comparison with the use of Waterguard in both the CG and IG groups. Of the other hypochlorite-based methods, PUR was used by less than 5% of both IG and CG and Aquatab was used by less than 5% of CG and 13.38% of IG. Ceramic filters were used by only about 5% of the IG and none of the CG, while SODIS was not used by either group. Traditional methods such as alum were not used by any IG or CG respondents and boiling was used by less than 10% of both groups (IG 5.56% and CG 7.79%; Appendix 4.3).

Appendix 4.4 shows that though the majority in both IG and CG treated their drinking water, the main reason given by those who did not treat water was the belief that water was clean and could not cause ill health, while the main reason given for treating water was also related to health and the cleanliness of water. For example, the effect of unclean water on health was mentioned by 350 (83.16%) of the IG and 54 (70.13%) of the CG.

Knowledge, attitudes and practices: water storage patterns

Almost all respondents, except for one in each study arm, allowed the interviewer to view their storage containers. Observations revealed that more than 60% of the main drinking water storage containers were clay pots in both IG 262 (65.99%) and CG 49 (63.64%), followed by jerry cans in both IG 59 (14.86%) and CG 14 (18.18%). Ceramic filters were used for storage by very few of the IG 14 (3.53%) and none of the CG. The Centre for Disease Control specially designed vessel was used by only 5 (1.26%) of the IG and none of the CG.

With regard to the storage vessel's safety features, Appendix 4.5 shows that most of the storage containers in both groups had mouth types which were wide enough for a hand to fit into: IG 332 (83.63%) and CG 73 (94.81%); very few had a tap in either IG 24 (6.05%) or CG 1 (1.30%).

The practices in relation to safe water management showed that most of the storage containers were covered at the time of the study in both the IG 385 (96.98%) and the CG 76 (98.70%): Containers were located in an elevated place, though the elevated places were less than 1 m high in most households: IG 256 (64.48%) and CG 61 (79.22%).

Appendix 4.6 shows that the predominant way of collecting water from the storage container was with a cup or calabash: IG 352 (88.66%) and CG 73 (94.81%). Only 16 (4.03%) and 1 (1.30%) in IG and CG respectively indicated that they used a spigot or tap to collect water from the storage vessel. The most common cleaning frequency was once a week by IG 352 (88.89%) and CG 73 (94.81%) and was mostly done without soap: IG 324 (82.23%) and CG 74 (96.10 %).

Appendix 4.7 shows that the collection container was different from the storage container in almost all the households in both study groups IG 387 (97.97%) and CG 76 (98.70%) and though most respondents IG 370 (93.20%) and CG 74 (96.10%) said it was important for the collection container to be covered during transportation, covers were only observed on IG 268 (67.51%) and CG 56 (72.23%).

Drinking water consumption-related knowledge, attitudes and practices

The assessment of the drinking water consumption patterns revealed family members older than 18 made up 40% of those who drank the treated drinking water in the IG and 30% in the CG. Children aged below five years made up about 25% in the IG and 20% in the CG.

In the IG, 213 (54.21%) and 31 (40.26%) of the CG respondents said that they drank between one and four cups of treated water daily (Appendix 4.8). Most of the respondents in both study groups (311 (89.11%) IG and 52 (85.25%) CG) said that they did not drink any untreated water.

The youngest child in about 60% of both the IG and CG households drank between one and three cups of treated water a day and as was observed with the adults, the youngest child did not drink untreated water in most of the households.

4.3.2 Adoption: Respondents' perceptions of household water treatment methods

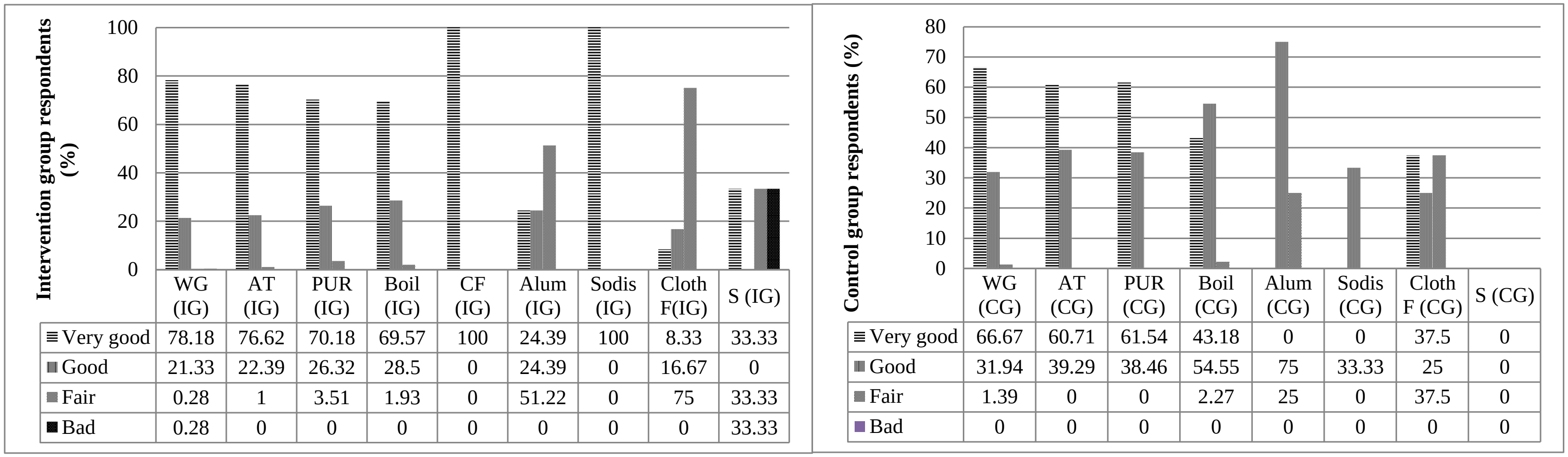
The respondents' perceptions about HWT that they had heard about is presented in this section and reported as the methods that had been promoted in the intervention communities (ceramic filters, PUR, Waterguard, Aquatab and SODIS), and the traditional methods used in rural communities (alum, boiling and filtration with cloth).

Perception of water treatment as good or bad

Respondents were asked to classify HWT methods as very good, good, fair or bad. The proportion of those who considered the technology as very good (Figure 4.1) shows that the IG 22 (100%) placed a very high perceived value on ceramic filters and a high value on Waterguard (78.18%), Aquatab (76.62%) and PUR (70.18%). No respondent had heard of ceramic filters in the CG. Using the same indicator, the CG placed a fairly high value on the three hypochlorite-based methods: Waterguard (66.67%), PUR (61.54%) and Aquatab (60.71%). Both the IG (69.67%) and the CG (54.55%) perceived boiling as a fairly high value product, but the IG considered SODIS to be a low value product and it was perceived by the CG as a very low value product (Figure 4.1).

Perceived effectiveness of water treatment in relation to killing germs in drinking water

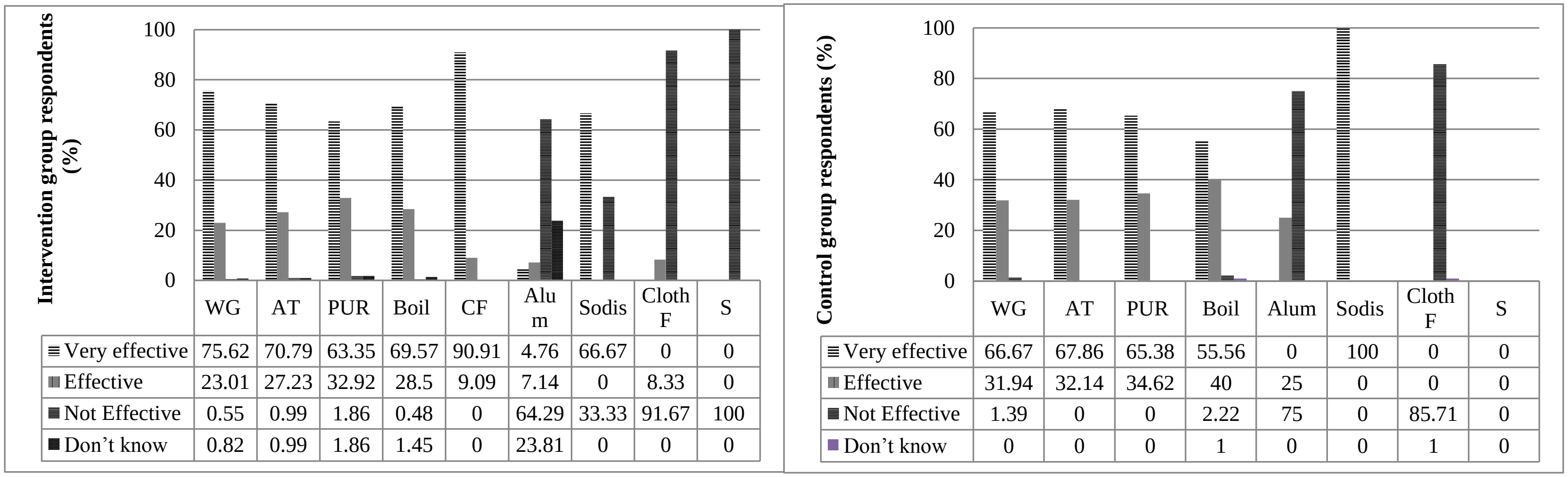
Figure 4.2 shows that the IG (90.91%) perceived ceramic filters as having very high value in terms of being very effective against germs. The IG (Waterguard (75.62%), Aquatab (70.79%) and PUR (63.35) viewed the hypochlorite-based methods as high value products: The CG also perceived them as high value products: Waterguard (66.67%), and PUR (65.38%) and Aquatab (67.86%). The CG (55.56%) attached a fairly high value to boiling while the IG (67.57%) perceived it as a high value product.



	WG (IG)	AT (IG)	PUR (IG)	Boil (IG)	CF (IG)	Alum (IG)	Sodis (IG)	Cloth F(IG)	S (IG)
≡ Very good	78.18	76.62	70.18	69.57	100	24.39	100	8.33	33.33
▥ Good	21.33	22.39	26.32	28.5	0	24.39	0	16.67	0
▨ Fair	0.28	1	3.51	1.93	0	51.22	0	75	33.33
■ Bad	0.28	0	0	0	0	0	0	0	33.33

	WG (CG)	AT (CG)	PUR (CG)	Boil (CG)	Alum (CG)	Sodis (CG)	Cloth F (CG)	S (CG)
≡ Very good	66.67	60.71	61.54	43.18	0	0	37.5	0
▥ Good	31.94	39.29	38.46	54.55	75	33.33	25	0
▨ Fair	1.39	0	0	2.27	25	0	37.5	0
■ Bad	0	0	0	0	0	0	0	0

Figure 4.1 Perception of the intervention and control respondents (%) of household water treatment method as very good, good, fair or bad. WG: Waterguard; AT: Aquatab; CF: Ceramic filters; Cloth F: Cloth filter; S: Settlement.



	WG	AT	PUR	Boil	CF	Alum	Sodis	Cloth F	S
≡ Very effective	75.62	70.79	63.35	69.57	90.91	4.76	66.67	0	0
▥ Effective	23.01	27.23	32.92	28.5	9.09	7.14	0	8.33	0
■ Not Effective	0.55	0.99	1.86	0.48	0	64.29	33.33	91.67	100
■ Don’t know	0.82	0.99	1.86	1.45	0	23.81	0	0	0

	WG	AT	PUR	Boil	Alum	Sodis	Cloth F	S
≡ Very effective	66.67	67.86	65.38	55.56	0	100	0	0
▥ Effective	31.94	32.14	34.62	40	25	0	0	0
■ Not Effective	1.39	0	0	2.22	75	0	85.71	0
■ Don’t know	0	0	0	1	0	0	1	0

Figure 4.2 Perception of the intervention and control respondents about the effectiveness household water treatment methods.

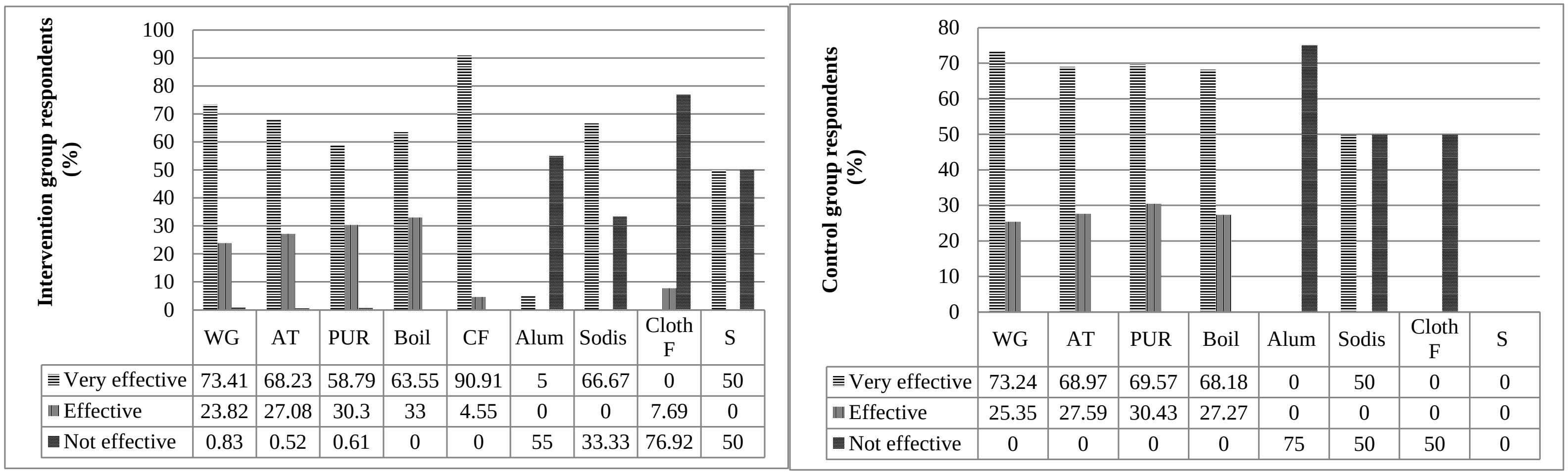
The majority in both study groups attached a very low value to the other traditional methods such as filtration with cloth, and settlement in relation to their effectiveness against germs (Figure 4.2).

Effectiveness of water treatment in relation to diarrhoea prevention

Figure 4.3 shows that the IG respondents rated ceramic filters the highest, with a very high perceived value, and attached a high value to Waterguard (73.41%), and Aquatab (68.23%), but placed a fairly high value on PUR (58.79%). As was observed in the IG, the CG respondents placed a high value on Waterguard (73.24%) and Aquatab. Unlike the IG, the CG attached a high value to PUR (69.57%). Boiling was the traditional method on which respondents placed a high value within both the IG (63.55%) and CG (68.18%). Both groups attached a very low value to alum, and filtration with cloth in terms of their effectiveness in preventing diarrhoea (Figure 4.3).

Perceived time cost of water treatment method

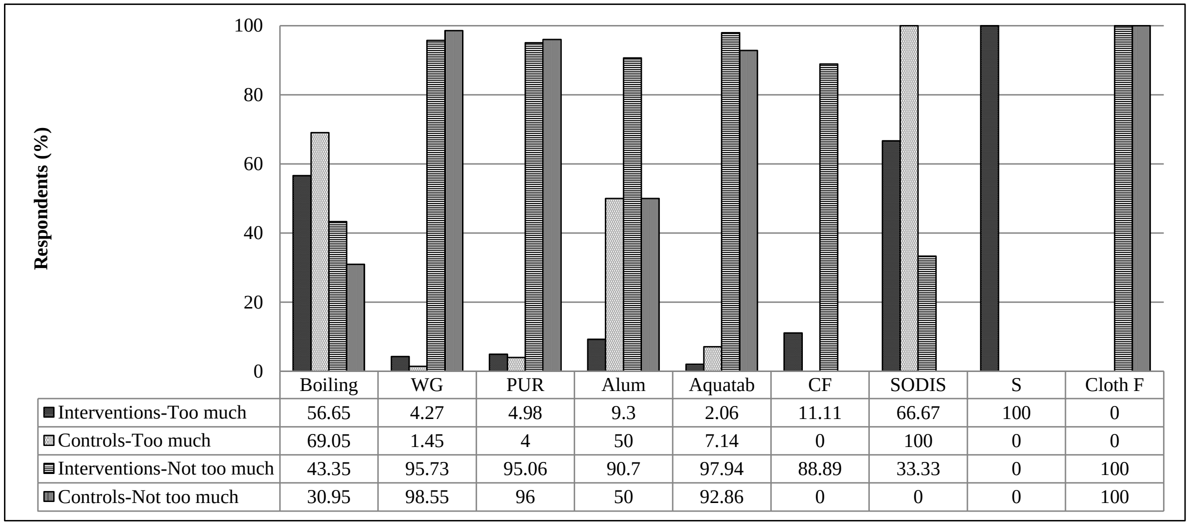
IG respondents attached a very high value to all the promoted technologies (> 90%) with respect to the time taken to treat water with them, except for SODIS which had a high perceived value (66.67%) placed on it by the few respondents that had heard of it. IG respondents considered boiling a fair value product. The CG had a similar value system; hypochlorite-based methods were perceived as very high value products, except for boiling which was perceived as low value (Figure 4.4).



	WG	AT	PUR	Boil	CF	Alum	Sodis	Cloth F	S
≡ Very effective	73.41	68.23	58.79	63.55	90.91	5	66.67	0	50
▥ Effective	23.82	27.08	30.3	33	4.55	0	0	7.69	0
■ Not effective	0.83	0.52	0.61	0	0	55	33.33	76.92	50

	WG	AT	PUR	Boil	Alum	Sodis	Cloth F	S
≡ Very effective	73.24	68.97	69.57	68.18	0	50	0	0
▥ Effective	25.35	27.59	30.43	27.27	0	0	0	0
■ Not effective	0	0	0	0	75	50	50	0

Figure 4.3 Perception of intervention and control respondents about the household water treatment methods effectiveness against diarrhoea. WG: Waterguard; AT: Aquatab; CF: ceramic filters; Cloth F: Cloth filter; S: Settlement.

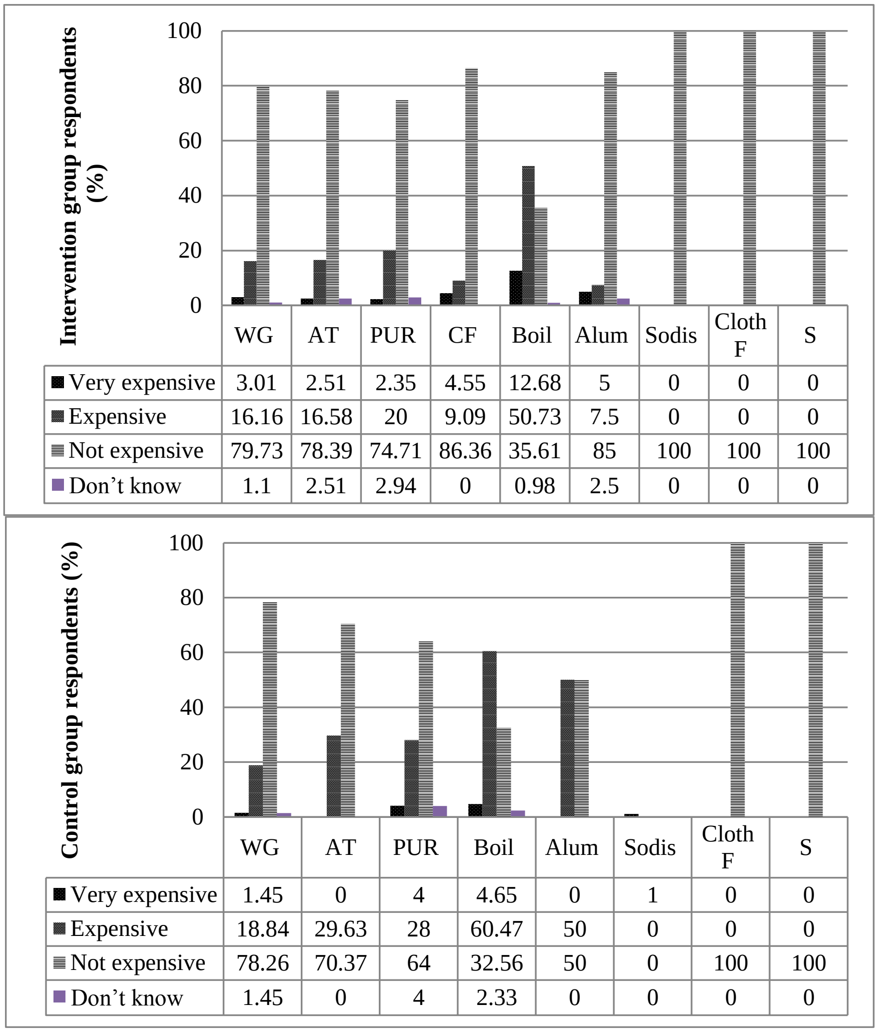


	Boiling	WG	PUR	Alum	Aquatab	CF	SODIS	S	Cloth F
■ Interventions-Too much	56.65	4.27	4.98	9.3	2.06	11.11	66.67	100	0
▨ Controls-Too much	69.05	1.45	4	50	7.14	0	100	0	0
▤ Interventions-Not too much	43.35	95.73	95.06	90.7	97.94	88.89	33.33	0	100
▥ Controls-Not too much	30.95	98.55	96	50	92.86	0	0	0	100

Figure 4.4 Perceptions about amount of time it takes to use household water treatment methods

Cost-related perceptions about water treatment methods

Figure 4.5 shows the perceptions about the monetary cost of the HWT methods. Ceramic filters had the highest percentage of respondents in the IG who perceived it as a very high value product (83.86%) and did not consider it expensive. The IG and CG considered the hypochlorite-methods as high-value products. Among the traditional methods, filtration with cloth was perceived as a very high value product (100%) by the IG, while boiling was perceived as a low value product (35.61%).

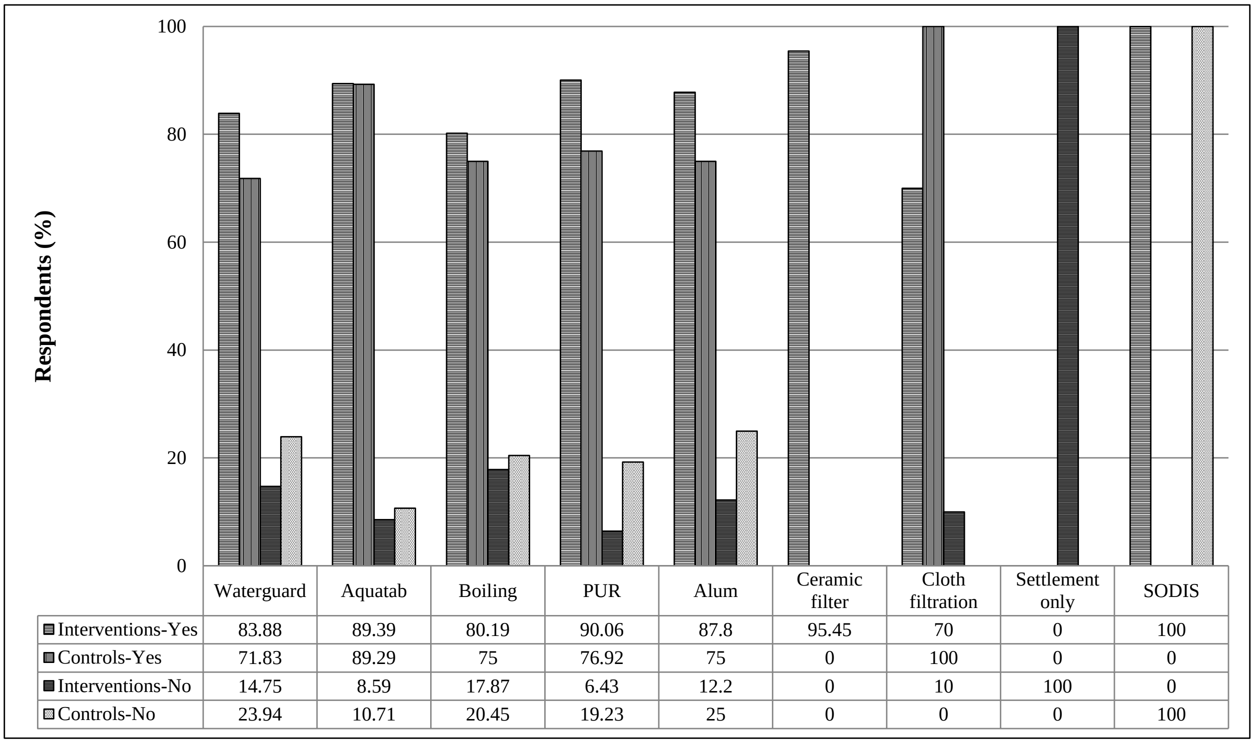


	WG	AT	PUR	CF	Boil	Alum	Sodis	Cloth F	S
■ Very expensive	3.01	2.51	2.35	4.55	12.68	5	0	0	0
■ Expensive	16.16	16.58	20	9.09	50.73	7.5	0	0	0
▤ Not expensive	79.73	78.39	74.71	86.36	35.61	85	100	100	100
■ Don’t know	1.1	2.51	2.94	0	0.98	2.5	0	0	0

	WG	AT	PUR	Boil	Alum	Sodis	Cloth F	S
■ Very expensive	1.45	0	4	4.65	0	1	0	0
■ Expensive	18.84	29.63	28	60.47	50	0	0	0
▤ Not expensive	78.26	70.37	64	32.56	50	0	100	100
■ Don’t know	1.45	0	4	2.33	0	0	0	0

Figure 4.5 Perceptions about costs of household water treatment methods. I: intervention; C: control; WG: Waterguard; AT: Aquatab; CF: ceramic filters; Cloth F: Cloth filter; S: Settlement.

Figure 4.6 shows that in terms of the technology's benefit outweighing its cost, the IG categorised SODIS as a very high value product (100%) but the few who had heard of SODIS in the CG perceived it as a very low value product (0%). The IG perceived the other promoted methods; ceramic filter and the hypochlorite-based products as very high value products (95.45%), PUR (90.06%), Aquatab (89.39%) and Waterguard (83.88%). The CG however rated only Aquatab as a very high value product (89.29%), while Waterguard (71.83%) and PUR (76.92%) were perceived as having a high value.



	Waterguard	Aquatab	Boiling	PUR	Alum	Ceramic filter	Cloth filtration	Settlement only	SODIS
▤ Interventions-Yes	83.88	89.39	80.19	90.06	87.8	95.45	70	0	100
▥ Controls-Yes	71.83	89.29	75	76.92	75	0	100	0	0
■ Interventions-No	14.75	8.59	17.87	6.43	12.2	0	10	100	0
▒ Controls-No	23.94	10.71	20.45	19.23	25	0	0	0	100

Figure 4.6 Perceptions about whether benefits outweigh cost of household water treatment method.

Perceived ability to use the method

When respondents were asked how well they thought they could use the HWT methods they had heard of, the IG perceived ceramic filters as a very high value product (87.50%) on the basis of the percentage of those who thought they could use it very well (Table 4.5). Though the IG perceived Waterguard as a high value product (69.95%), the CG perceived it as only having a fairly high value (56.3%).

Table 4.5 Respondents' perceptions about their ability to use household water treatment method they had heard about.

HWT Methods	Interventions												Controls											
	Very Well		Well		Fairly		Poorly		Don’t know		Total		Very Well		Well		Fairly		Poorly		Don’t know		Total	
	n	%	N	%	n	%	N	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Waterguard	256.0	70.0	103.0	28.1	3.0	0.8	0.0	0.0	4.0	1.1	366.0	100.0	40.0	56.3	31.0	43.7	0.0	0.0	0.0	0.0	0.0	0.0	71.0	100.0
Aquatab	118.0	59.0	76.0	38.0	3.0	1.5	0.0	0.0	3.0	1.5	200.0	100.0	12.0	42.9	16.0	57.1	0.0	0.0	0.0	0.0	0.0	0.0	28.0	100.0
Boiling	127.0	61.4	78.0	37.7	2.0	1.0	0.0	0.0	0.0	0.0	207.0	100.0	18.0	40.9	26.0	59.1	0.0	0.0	0.0	0.0	0.0	0.0	44.0	100.0
PUR	75.0	44.5	81.0	48.2	6.0	3.6	1.0	0.6	5.0	3.0	168.0	100.0	11.0	42.3	14.0	53.9	1.0	3.9	0.0	0.0	5.0	2.6	31.0	102.6
Alum	22.0	53.7	17.0	41.5	2.0	4.9	0.0	0.0	0.0	0.0	41.0	100.0	1.0	25.0	3.0	75.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	100.0
Ceramic filter	21.0	87.5	2.0	8.3	0.0	0.0	0.0	0.0	1.0	4.2	24.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Filtration with sand	9.0	0.0	1.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Filtration with cloth	6.0	46.2	7.0	53.9	0.0	0.0	0.0	0.0	0.0	0.0	13.0	100.0	3.0	42.9	4.0	57.1	0.0	0.0	0.0	0.0	0.0	0.0	7.0	100.0
Settlement only	1.0	50.0	0.0	0.0	1.0	50.0	0.0	0.0	0.0	0.0	2.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SODIS	1.0	50.0	0.0	0.0	1.0	50.0	0.0	0.0	0.0	0.0	2.0	100.0	1.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	100.0

n: frequency

Use by family and friends

Table 4.6 shows that the IG perceived ceramic filters as a very high value product in terms of their use by a high proportion of other family members and friends (90.91%). Though the IG also perceived Waterguard (87.05%) as a very high value product, they perceived Aquatab (78.39%) and PUR (72.70%) as high value products. The CG perceived the three hypochlorite-based methods as high value products: Waterguard (81.77%), PUR (80.77%) and Aquatab (78.57%).

Table 4.6 Use of household water treatment methods by family and friends.

HWT method	**Intervention**						**Control**					
	Yes		No		Don't know		Yes		No		Don't know	
	n	%	n	%	n	%	n	%	n	%	n	%
Waterguard	316	87.1	1	0.3	46	12.7	58	81.7	0	0	13	18.3
Aquatab	156	78.4	3	1.5	40	20.1	22	78.6	0	0	6	21.4
PUR	125	72.7	8	4.7	39	22.7	21	80.8	0	0	5	19.2
Boiling	151	73.0	7	3.4	49	23.7	29	65.9	0	0	15	34.1
Filtration with ceramic filter	20	90.9	0	0	2	9.1	0	0	0	0	0	0
Addition of alum	22	56.4	3	7.7	14	35.9	3	75.0	0	0	10	25.0
Filtration with cloth	5	41.7	0	0	7	58.3	4	57.1	0	0	3	42.9
Settlement only	0	0	1	100	0	0	0	0	0	0	0	0
SODIS	0	0	0	0	2	100	0	0	0	0	1	100

HWT: household water treatment method; n = sample size; values have been rounded to 1 decimal place.

Ease of accessing water treatment materials

The IG perceived ceramic filters as a product of fairly high value (59.09%) in terms of the ease with which its materials can be accessed. This was the lowest perceived value attached to the promoted methods. The IG and CG rated the hypochlorite-based methods as high value products in this regard both study groups, 35.47% in IG and 25% in CG, perceived boiling as a product of low value in this regard (Figure 4.7).

Table 4.7 shows that Waterguard would be the technology chosen if ease of accessing materials was used as the selection criterion ($p < 0.01$; Table 4.7).

Table 4.7 The influence of respondents' perceptions about the ease of accessing material for water treatment method on the adoption of Waterguard.

Treatment method	**Adjusted OR**	**95% CI**		**p-value**
Boiling	1.02	0.64	1.64	0.92
Ceramic filters	0.20	0.02	2.04	0.17
Waterguard	0.34	0.15	0.77	***0.01***
Aquatab	0.90	0.34	2.37	0.83
PUR	1.52	0.59	3.87	0.36

Italics shows statistical significance at $p < 0.05$, at a 95% confidence interval; Adjusted OR: Adjusted odds ratio

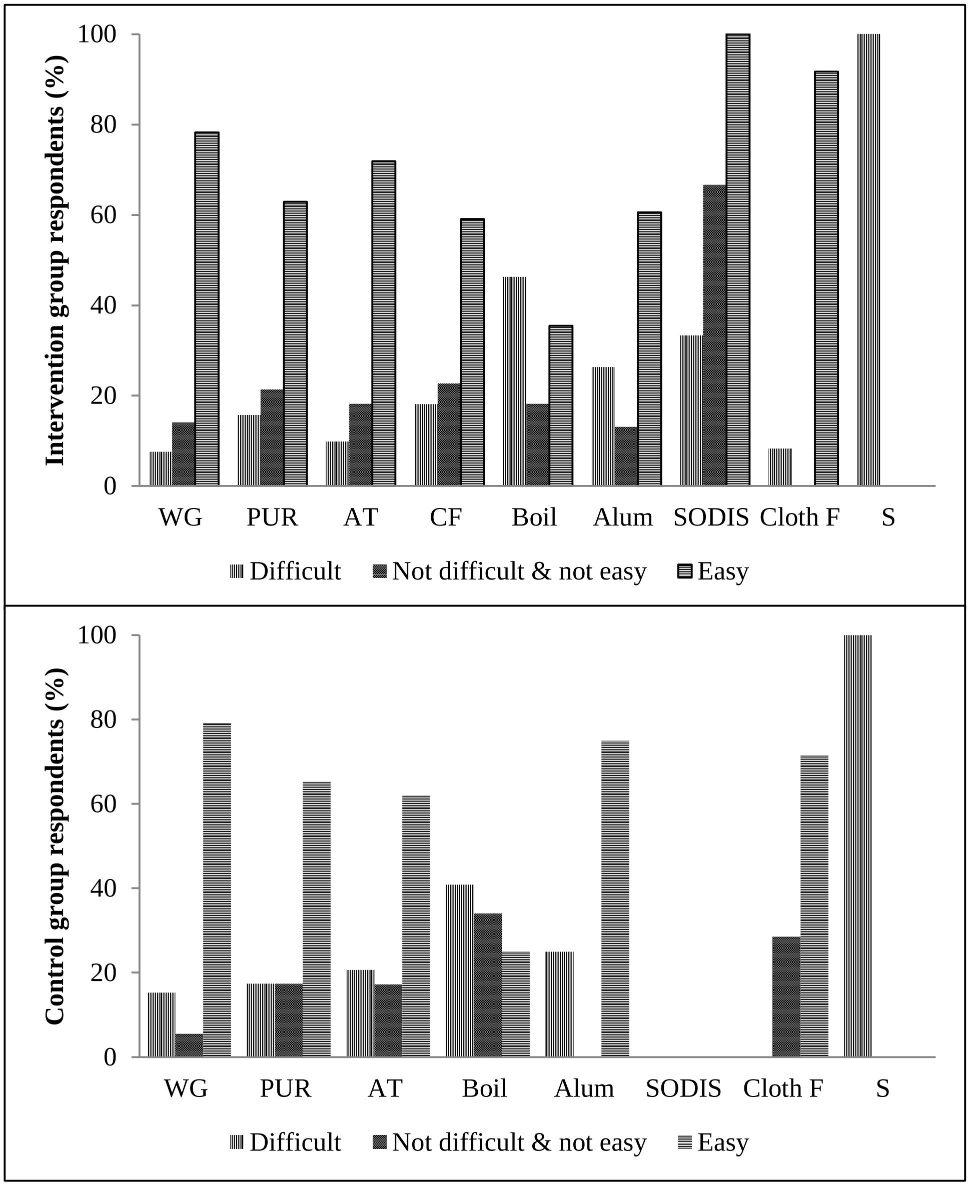
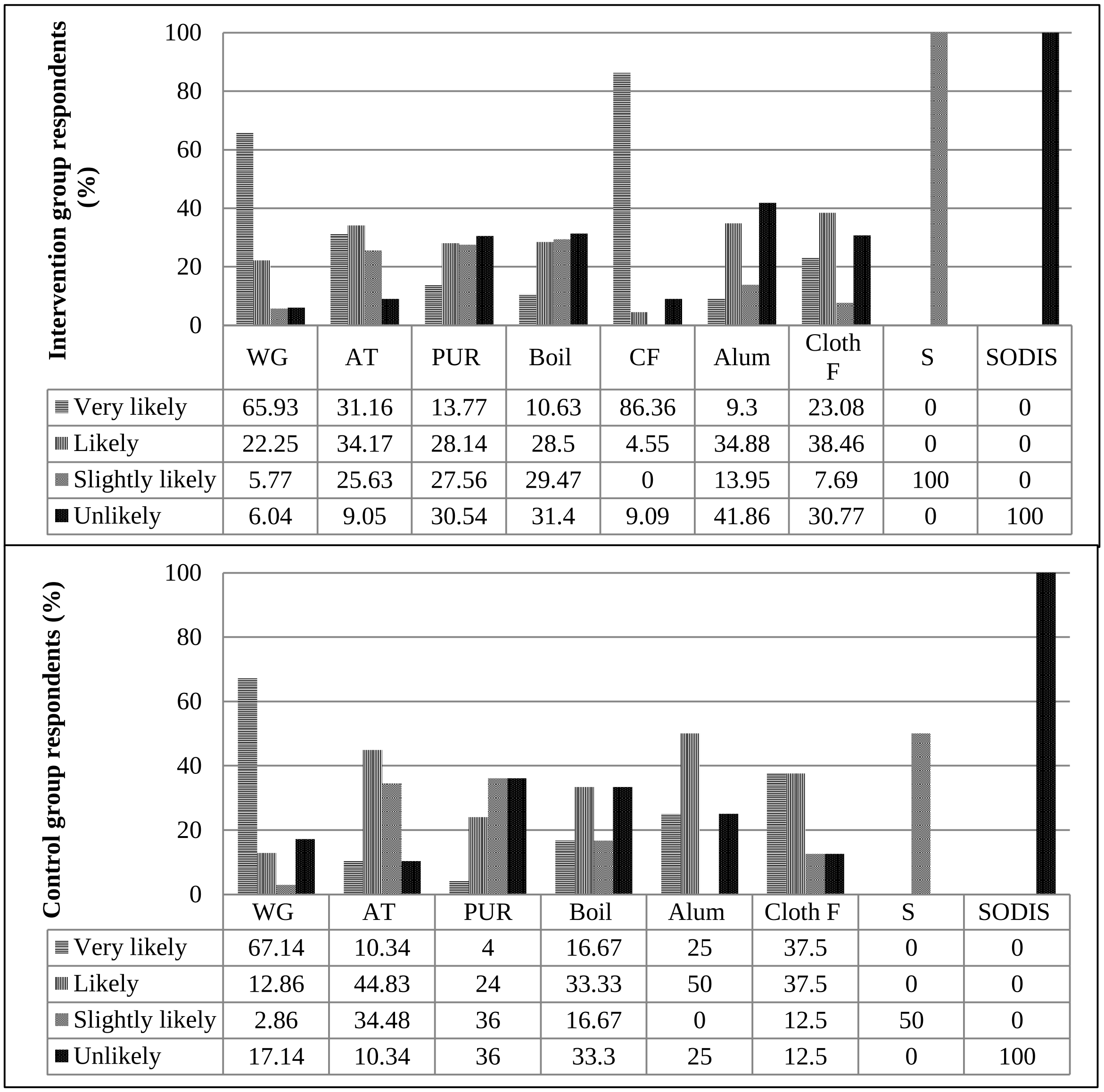


Figure 4.7 Perceptions about ease of accessing materials for HWT methods.
WG: Waterguard; AT: Aquatab; CF: ceramic filters; Cloth F: Cloth filter;
S: Settlement.

Reported likelihood of using treatment method regularly in the next two weeks

The IG considered the ceramic filter as a product that they were very likely to use within the next two weeks (86.36%) and perceived it as a very high value product. Both the IG (65.93%) and CG (67.14%) perceived Waterguard as a high value product while the two groups perceived PUR as a very low value product.



	WG	AT	PUR	Boil	CF	Alum	Cloth F	S	SODIS
▤ Very likely	65.93	31.16	13.77	10.63	86.36	9.3	23.08	0	0
▥ Likely	22.25	34.17	28.14	28.5	4.55	34.88	38.46	0	0
▒ Slightly likely	5.77	25.63	27.56	29.47	0	13.95	7.69	100	0
■ Unlikely	6.04	9.05	30.54	31.4	9.09	41.86	30.77	0	100

	WG	AT	PUR	Boil	Alum	Cloth F	S	SODIS
▤ Very likely	67.14	10.34	4	16.67	25	37.5	0	0
▥ Likely	12.86	44.83	24	33.33	50	37.5	0	0
▒ Slightly likely	2.86	34.48	36	16.67	0	12.5	50	0
■ Unlikely	17.14	10.34	36	33.3	25	12.5	0	100

Figure 4.8 Likelihood of use of household water treatment methods in the two weeks after the study.

WG: Waterguard; AT: Aquatab; CF: ceramic filters; Cloth F: Cloth filter; S: Settlement.

Perceived value of household water treatment methods based on the respondents' perceptions of the adoption-related determinants

Table 4.8 shows the scores scored by each water treatment method per indicator and helps to identify the strong and weak aspects of the technology from the study communities' perspectives. Figure 4.9 shows the total percentage points scored by the water treatment methods in terms of perceived value attached to them by the respondents. The perceived value attached to the promoted methods are similar between the two study groups — likely to highly likely (IG) and fairly likely to likely (CG). The likelihood of adoption of the traditional methods is also similar in the two groups — unlikely to fairly likely (IG) and highly unlikely to fairly likely (CG).

Table 4.8 Points scored by household water treatment methods according to adoption-related perceptions of intervention and control group respondents.

Perception	**Intervention**									**Control**							
Adoption-related determinants	WG	AT	Boil	PUR	CF	ALUM	SODIS	CLOTH F	S	WG	AT	BOIL	PUR	ALUM	SODIS	CLOTH F	S
Very good	8	8	7	7	10	3	10	1	4	7	7	5	7	0	1	4	1
Effectiveness against	8	7	8	7	10	1	7	1	1	7	6	7	7	1	0	0	0
Effectiveness against diarrhoea	8	7	7	6	10	1	7	1	1	8	7	7	7	1	5	1	1
Time taken	10	10	5	10	9	10	4	10	1	10	10	4	10	5	1	10	1
Perceived costs	8	8	4	8	9	9	10	10	10	8	8	4	7	5	1	10	10
Benefits outweigh costs	9	9	8	9	10	9	10	7	1	8	9	8	8	8	1	1	1
Ease of accessing	8	8	4	7	6	7	10	10	1	8	7	4	7	7	1	8	1
Perceived ability to use	7	6	7	5	9	6	5	5	5	6	5	5	5	3	10	5	1
Use by family and friends	9	8	8	8	10	6	1	5	1	9	8	7	9	8	1	6	1
Likelihood of use in next 2 weeks	7	4	2	2	9	1	1	3	1	7	1	2	1	3	1	4	1
Total points	82	75	60	69	92	53	65	53	26	78	68	53	68	41	22	49	18
Percentage	82	75	60	69	92	53	65	53	26	78	68	53	68	41	22	49	18

WG: Waterguard; AT: Aquatab; Cloth F: cloth filter; CF: ceramic filter; S: settlement. Maximum points possible = 100; Total percentage = total points scored/maximum points possible x 100; Points interpretation: Very low: 0–20%; low: 21–40%; fairly high: 41–60%; high: 61–80%; Very high: 81–100%

4.3.3 Compliance: sustained use of water treatment method

Ceramic filters (only in the IG), Waterguard, PUR, Aquatab and boiling are the methods reported for their compliance-related perceived value. This is because they were the main methods the study households used.

a) Self-reported main water treatment method

The IG and CG respondents perceived Waterguard as a high value product in relation to their self-reported use of their main HWT method, while the IG placed a low value on ceramic filters. The IG and CG respondents placed a very low perceived value on the other methods (Table 4.9).

b) **Observed water treatment method**

Table 4.7 indicates that when the respondents' self-reporting of their main HWT method use was compared with the actual sighting of the products, IG users placed a very high perceived value on ceramic filters as all users could show their filters (100%); on PUR (93.33%) and Aquatab (90.57%). The CG attached a comparatively higher perceived value of very high (86.79%) to Waterguard than the IG. This indicator was not used to assess boiling as the product could not be observed (Table 4.9).

c) **Self-reported use in the previous seven days before the study**

The IG attached a very high perceived value to ceramic filters, and both the IG (80.51%). and CG (94.34%) perceived Waterguard as a very high value product. (Table 4.9).

d) Number of times water was not treated in the previous month of the study

Table 4.10 indicates that when the perceived value of the HWT methods was assessed on the basis of how often the users forgot to treat their water, the IG placed the highest perceived value (very high) on ceramic filters with no user forgetting to treat water in the month before the study. The perception about boiling also differed between the IG (high value) and CG (low value).

Table 4.9 Self-reported water treatment, observed and used in the past seven days.

Treatment methods	**Self-reported main water treatment method n = 473**				**Observed treatment method**				**Used treatment method in past 7 days***			
	Intervention n		Control n =		Intervention n		Control		Intervention		Control	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
Waterguard	277	69.95	53	68.83	209	75.45	46	86.79	223	80.51	50	94.34
Aquatab	53	13.38	3	3.90	48	90.57	1	33.33	46	86.79	1	33.33
PUR	15	3.79	2	2.60	14	93.33	1	50.00	14	93.33	1	50.00
Boiling	22	5.56	6	7.79	n/a	n/a	n/a	n/a	19	86.36	4	66.67
Filtration	20	5.05	0	0	20	100.00	0	0.00	20	100.00	0	0.00
Filtration	1	0.25	1	1.30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
*Others	6	1.52	12	15.58	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Don't know	2	0.51	0	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total	396	100.00	77	100	291	100	48	100	322	100	56	100

Percentages were calculated in relation to the self-reported frequencies. *others were households that did not treat water and one household that uses a candle filter; N/A: Not applicable; Freq: Frequency.

Table 4.10 Number of users that omitted to treat water with main household water treatment method in past one month.

Variable	**Intervention**				**Control**			
Households that did not treat water in the previous month	Yes		No		Yes		No	
	Freq	%	Freq	%	Freq	%	Freq	%
Waterguard n = 317	97.0	36.7	167.0	63.3	16.0	30.2	37.0	69.8
IG = 264; CG = 2								
Aquatab n = 54	12.0	23.1	40.0	76.9	1.0	50.0	1.0	50.0
IG = 52; CG = 2								
PUR n = 17	7.0	43.8	9.0	56.3	1.0	100.0	0.0	0.0
IG = 16; CG = 1								
Boiling n = 29	6.0	26.1	17.0	73.3	3.0	50.0	3.0	50.0
IG = 23; CG = 6								
Ceramic filters n = 20	0.0	0.0	20.0	100.0	0.0	0.0	0.0	0.0
IG = 20; CG= 0								

Perceived value of household water treatment methods based on the users' sustained use of the methods

Table 4.11 shows the points scored per indicator for each method. Within the IG, using the likelihood scale (Table 4.3) the total percentage points suggest that ceramic filter, Waterguard, Aquatab and PUR have a high likelihood of sustained use if adopted, while boiling has a moderate likelihood of sustained use. Within the CG, Waterguard has a high likelihood of sustained use, while Aquatab, PUR and boiling have a moderate likelihood of sustained use.

Table 4.11 Points scored by household water treatment methods according to sustained use-related perceptions of intervention and control group respondents.

Determinant	**Intervention**					**Control**			
Sustained use	WG	AT	Boil	PUR	CF	WG	AT	Boil	PUR
Self-reported treatment method	7	2	1	1	1	7	1	1	1
Sighting of HWT method	8	10	N/A	10	10	8	10	N/A	10
Treatment of water within the past 7 days	9	9	9	10	10	10	4	7	5
Number of times household forgot to treat water in the past one month	7	8	8	6	10	7	5	5	1
Total points	31	29	18	27	31	32	20	13	17
Total percentage	77.5	72.5	60	67.5	77.5	80.00	50.00	43.33	42.50

WG: Waterguard; AT: Aquatab; CF: ceramic filter; Maximum points possible = 40 (except for boiling which was 30); Total percentage = total points scored/maximum points possible x 100; Points interpretation: Very unlikely: 0–20%; unlikely: 21–40%; fairly likely: 41–60%; likely: 61–80%; Very likely: 81–100%.

4.3.4 Compliance: correct use of water treatment method

The correct use of water treatment methods was assessed by examining the respondents' knowledge of the critical steps necessary to use each method effectively and by determining the free chlorine residual levels of stored water samples from 152 households that use hypochlorite-based methods. Table 4.12 indicates that in the IG, two out of every five (40%) households that used Waterguard were conversant with the three critical steps for effective use, followed by PUR with one out of every three (33.3%), Aquatab (15.09%), boiling (4.55%), and lastly ceramic filters (0%) being conversant with the critical steps. Within the CG, no household used ceramic filters, about one third of Waterguard users were conversant with the method, followed by boiling (16.67%) while Aquatab and PUR had no respondent who was conversant with their effective use. The study groups did not differ statistically in their knowledge about the critical steps for any of the water treatment methods (Table 4.12).

In the IG households, adequate levels of free chlorine residuals were detected in the drinking water storage containers of 70.75% of the Waterguard households that were tested, 83.3% of the Aquatab households, and 66.67% of the PUR households (Appendix 4.9).

Table 4.12 Users' familiarity with critical steps for effective use of current household water treatment method

Method	Conversant				Non-conversant				Test of significance		
	Intervention		Control		Intervention		Control				
	n	%	n	%	N	%	n	%	p-value	OR	95% CI
Waterguard n = 330 IG = 277; CG = 53	111	40.1	18	34	166	59.9	35	66.1	0.4	1.3	0.7–2.4
Aquatab n = 56 IG = 53; CG = 3	8	15.1	0	0	45	84.9	3	100	1	N/A	N/A
PUR n = 17 IG = 15; CG = 2	5	33.3	0	0	10	66.7	2	100	1	N/A	N/A
Boiling n = 28 IG = 22; CG = 6	1	4.6	1	16.7	21	94.5	5	83.3	0.4	0.2	0.01–4.5
Ceramic filters n = 20 IG = 20; CG = 0	0	0	0	0	20	100	0	0	N/A	N/A	N/A

N/A: Not applicable n: frequency; IG: intervention group; CG: control group.

Perceived value of household water treatment methods based on the users' correct use of the methods.

The household water treatment methods were perceived as low value products when assessed by how correctly the households used them and the percentage points scored indicated that it was either very unlikely or unlikely that either of the two study groups would use the HWT methods correctly.

4.3.5 Compliance: characteristics of household water treatment methods that current users like

Users in both groups most frequently mentioned the following four HWT characteristics as the ones that they liked: efficacy (IG: 35.44% and CG: 35.41%); affordability (IG: 18.25% and CG: 18.05%); easy access to the HWT materials (IG: 13.49% and CG: 10.42%) and time taken (IG: 12.48% and CG: 22.00%). Other characteristics that were mentioned by a lower percentage of respondents were the taste of the water, no special equipment required for its use, respondent's ability to use, and the absence of harmful chemicals. The four most mentioned characteristics were used to assess the perceived value the respondents attached to the HWT methods.

Both study groups perceived Waterguard and Aquatab as low value products in terms of efficacy; while the IG perceived PUR as a fairly high value product but the CG perceived it as a low value product (Appendix 4.10). Both groups perceived boiling as a product of fairly high value in terms of its efficacy.

In terms of the ease with which materials for the HWT can be obtained, Appendix 4.10 shows that the IG perceived the ceramic filter as a product of very low value (0%). Both study groups perceived all the HWT technologies as being of either low or very low value in this regard. In terms of affordability, all the HWT products were perceived by users as either very low or low value products by both study groups (Appendix 4.10).

Similarly, Appendix 4.10 shows that all the HWT products were perceived by users as either very low or low value products in terms of the time taken to use them. Users in both IG and CG perceived boiling as a product of very low value as was Waterguard in IG (13.52%) and CG (25.6%).

Perceived value of household water treatment methods based on characteristics current users like about the method

All the household water treatment methods were perceived as very low or low value products in terms of the ease to access materials, affordability and time it takes to use. They were ranked higher in terms of efficacy except for ceramic filters within the IG, and boiling and PUR within the CG (Table 4.13). Therefore they all fall into the likelihood scale of very unlikely and unlikely to be complied with on the basis of the combination of the four characteristics.

Table 4.13 Likelihood of compliance based on current users' liking of four characteristics.

Determinant	**Intervention**					**Control**			
Users' likes about HWT method	WG	AT	Boil	PUR	CF	WG	AT	Boil	PUR
Efficacy	4	4	6	6	1	4	4	5	3
Ease of accessing materials	2	2	1	1	1	1	2	3	1
Affordability	2	3	1	3	2	2	2	2	3
Quick to use	2	2	1	1	1	3	2	1	1
Total points	10	11	9	11	5	10	10	10	8
Total percentage	25	27.5	22.5	27.5	12.5	25	25	25	20

WG: Waterguard; AT: Aquatab; CF: ceramic filter; Maximum points possible = 40. Total percentage = total points scored/maximum points possible x 100.; Points interpretation: Very unlikely: 0–20%; unlikely 21–40%; fairly likely 41–60%; likely 61–80%; Very likely 81–100%.

4.3.6 Performance of household water treatment methods in relation to adoption, compliance and sustained use

Figure 4.9 shows the summary performance of each HWT method in relation to the adoption and compliance indicators. The IG perceived the ceramic filter as a very high value product in terms of the adoption-related determinants (92%), a high value product for sustained use (77.5%), but a very low value product in terms of correct use (0%), and user liking (12.5%) of its characteristics in relation to efficacy, affordability, ease of accessing materials and time it takes. On the whole, the IG perceived it as a high value product as shown by the summary percentage (67.9%), and were likely to adopt it and comply with its use.

Figure 4.9 shows that the IG perceived Waterguard as a very high value product in terms of adoption-related criteria (82%), and the CG perceived it as a high value product (78%). On the whole, Waterguard was perceived as a high value product by both the IG (66.8%) and CG (65.3%), who were likely to adopt it and comply with its use.

Both the IG (75%) and CG (68%) perceived Aquatab as a high value product in terms of the adoption-related criteria. In terms of sustained use, the IG (72.55%) attached a high perceived value to it while the CG (50%), attached a fairly high value. On the whole, the IG (62.1%) attached a high perceived value to it and were likely to adopt it and comply with its use, and the CG (52.1%) a fairly high perceived value, and were fairly likely to adopt it and comply with its use (Figure 4.9).

Both the IG (69%) and CG (68%) perceived PUR as a high value product in terms of the adoption-related criteria. Both IG and CG users perceived it as a low value product in terms of how they liked its cost, time taken to use and ease of accessing materials. On the whole both IG (58.4%) and CG (49.5%) perceived PUR as a product with a fairly high value and were fairly likely to adopt it and comply with its use (Figure 4.9).

Both the IG (60%) and CG (53%) perceived boiling as a fairly high value product in terms of the adoption-related criteria. Both IG and CG perceived it as a low value product in terms of their liking of its cost, time taken and ease of accessing materials. On the whole, both IG (48.9%) and CG (43.3%) perceived boiling as a product of fairly high value and were fairly likely to adopt it and comply with its use (Figure 4.9).

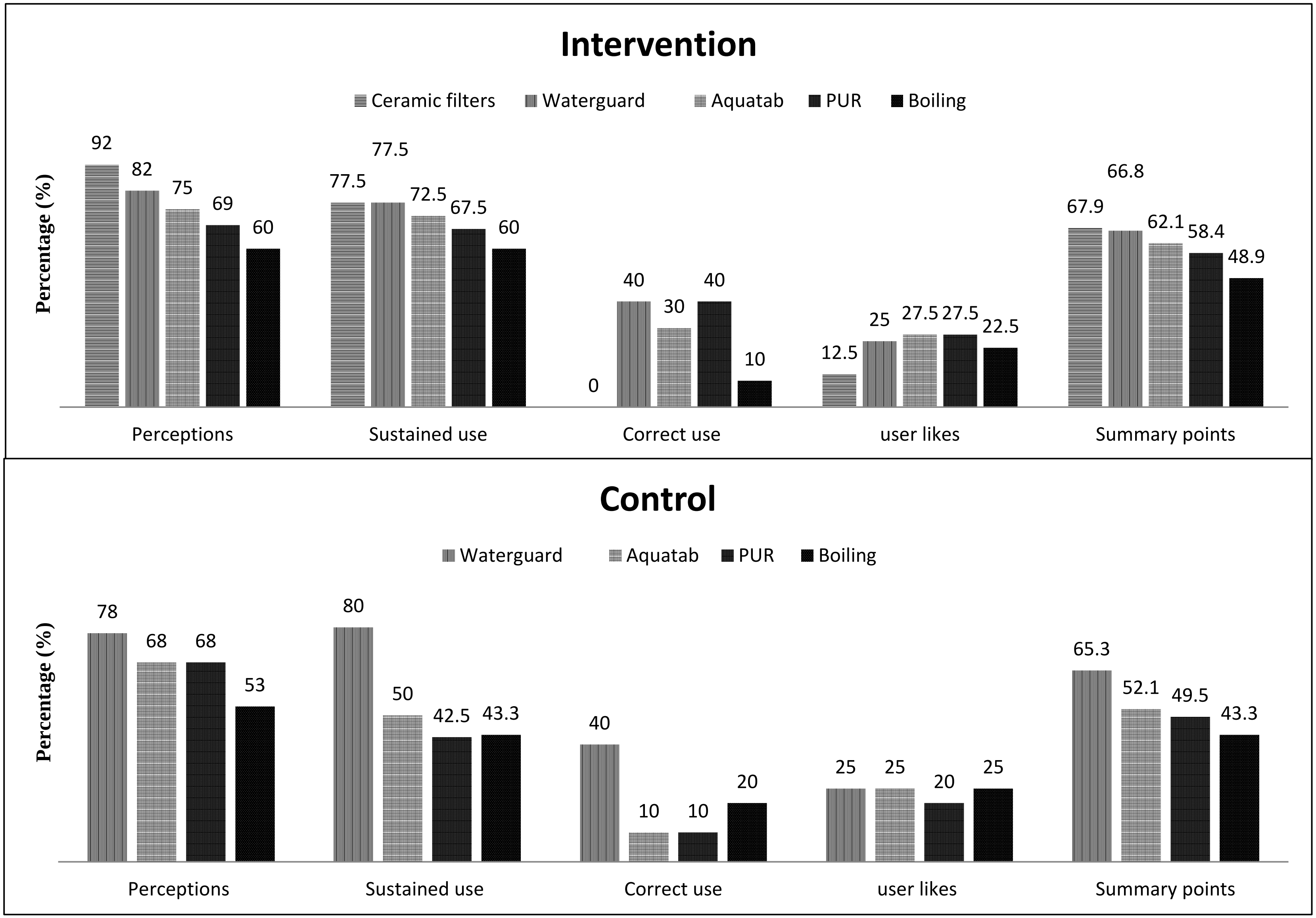


Figure 4.9 The perceived value (total percentage) attached to selected HWT technologies by intervention and control groups

4.4 Discussion

Behavioural factors affect the likelihood of HWT adoption and compliance. Consequently behavioural factors such as: gender roles and compliance, the KAP on household water treatment, storage practices and consumption patterns are first discussed. A discussion of findings on the likelihood of adoption in relation to perceived value follows.

4.4.1 General overview

Gender roles

The findings that women are mainly responsible for keeping water clean in both the IG and CG agree with the observation by the WHO/UNICEF (2010) that in 64% of the households in 45 developing countries, women bear the burden of collecting drinking water, while men bear this responsibility in 24% of the households. Since the criterion used by the study households to select the person who keeps the water clean was the most senior female in the house and not level of education, it is unlikely that those selected could comply with the requirements for optimum use of the HWT technologies.

Knowledge, attitudes and practices: household water treatment

The study communities' poor knowledge about the suitability of different HWT methods for the various types of water sources will also affect the effectiveness of the HWT technologies in the real-world context. For example, even though the visual clarity of water was what most IG and CG respondents mentioned that they expected of safe drinking water, Waterguard was the main HWT method used in the community, though this method does not reduce turbidity (Rangel *et al*., 2003; Crump *et al.*, 2004), and its disinfection efficacy is reduced by the high turbidity of the surface water sources which serve as the study communities' main drinking water source (Sobsey *et al*., 2009). However, PUR, the HWT product which reduces turbidity and disinfects water (Lantagne *et al.*, 2006) was used by only 3.79% in the IG and 2.6% in the CG. This study's observation of a similar gap between user knowledge and choice of HWT method was reported by Albert *et al.* (2010) in a study in western Kenya, where the expected higher use of PUR by households that use surface water sources compared to users of the less turbid rainwater and piped water was not observed.

This study's observation of a gap in knowledge about the appropriate choices is disconcerting given that knowledge about an HWT method and its use by family and friends are variables that influence adoption (Meierhofer and Landolt, 2009; Kraemer and Mosler, 2010). This is because unfulfilled expectations either from personal or peer experience will result in the user attributing a low perceived value to the product, resulting in poor adoption and compliance and an increase in the incidence of water-borne diseases. This study's findings further underscore caution by Sobsey *et al. (*2009) against the promotion of Waterguard and similar hypochlorite-based HWT in turbid water sources, attributing the observed increase in water-borne diseases to such HWT promotion.

Knowledge, attitudes and practices: storage practices

The use of clay pots

About two-thirds of both the IG and CG households used clay pots as the main drinking water storage container, a practice which Wright *et al.* (2004) noted contributes to higher levels of contamination. However these findings are not surprising as households would prefer cheaper and more culturally familiar storage containers. In light of the households' preference for clay, such traditional storage containers can be modified to improve storage.

Safe storage container features

This study found that most of the storage containers did not have the recommended safe storage features. Most storage containers in both the IG and CG households were wide mouth types (Appendix 4.5), and most respondents took water from the storage container with a cup or calabash rather than from a tap (Appendix 4.6). Clasen and Bastable (2003) found similar practices in a study in Liberia where most households dip a cup or other utensil (78.8%) into their storage container, rather than use a tap or spigot (12.9%). The study findings differ from the findings in a northern Nigeria study where the majority, 79.5% of respondents, reportedly used containers with long handles, and separate containers for taking water were observed in 81.9% of the households (Onabolu *et al*., 2011).

Decanting from collection container to a storage container

In addition to the material of the storage container and its safety features, the study observed that the storage container was different from the collection container in almost all the households in both study groups (Appendix 4.7), which may also contribute to water quality deterioration. This is consistent with the findings of Clasen and Bastable (2003) and Wright *et al*. (2004) about the factors that contribute to water quality deterioration.

Knowledge, attitudes and practices: Water consumption patterns

The quantity of water that can be produced in one cycle of use was a criterion used by Sobsey *et al.* (2008), in a review of studies of the efficacy of HWT. The authors based this on the ability of the technology to treat a minimum of 20 l of water per household per day, assuming the consumption of 5 l/capita/day in a four-person household. Lantagne *et al.* (2009) found it arbitrary, but Sobsey *et al.* (2009) responded that it could only be reviewed if contrary evidence was available. This study found that the quantity of 20 l daily was excessive, since the IG had a mean household size of 6 persons who drank between 250 ml and 1000 ml of water/capita/day; i.e. 3–6 l/day/household. The CG had a mean household size of 5 persons, who drank between 250 ml and 1000 ml/capita/day i.e. 1.25–5 l/day/household. On this basis, the review by Sobsey *et al.* (2008) should therefore not have ranked SODIS low on this basis.

This study's observations about non-compliance with safe storage features have implications for effective water treatment, given that hygienic storage practices are critical in maintaining water quality and preventing recontamination (Mintz *et. al.*, 1995; Wright *et al.*, 2004; Tumwine, 2005; Levy *et al*., 2008; Onabolu *et al.*, 2011).

4.4.2 Adoption and compliance with HWT

This study found that Waterguard was the treatment most people were aware of and the most frequently used in the two study groups, suggesting that awareness of a household water treatment method is a crucial first step towards its usage. This is in line with the observation by

Wood *et al.* (2011) that a consistent HWT user moves through three stages of behaviour: awareness of the water treatment method and its perceived value; use of the product, which if perceived as having a high enough value, will lead to the third stage: the inculcation of HWT use into the users' daily routine. This study found that even though Waterguard was used by the majority of the two study groups, there was a gap between the level of awareness and the level of its use: almost all the IG and CG had heard about Waterguard but just a little over two-thirds were using it. Similarly, although about half of both study groups had heard about boiling, less than 10% were treating their water in this way. This is consistent with Wood *et al.* (2011) that awareness of a water treatment method may translate into higher brand recognition but not necessarily into usage.

Given that awareness does not necessarily lead to adoption, nor does adoption automatically lead to consistent use, this study's findings on the perceived value attached to HWT give an indication of the *likelihood* of moving from adoption to compliance by users in a real-world context. Though respondents perceived Waterguard as a very high value product in terms of the adoption-related criteria, users in both study groups perceived it as a lower value product in terms of correct use and the critical compliance-related determinants: affordability and ease of accessing materials. The implication for HWT is that even though users hear about Waterguard and adopt it, its low perceived value will reduce the likelihood of the user's move from the adoption stage to sustained use. The study findings show that in the IG the likelihood of its adoption is 'highly likely' but the likelihood of sustained use reduces to 'likely' (Figure 4.9).This interpretation agrees with Sobsey *et al. (*2008) that hypochlorite-based methods (such as Waterguard) do not achieve sustained use once the intervention ends and is similar to the observation that though 65% of the mothers identified in a survey in Malawi had heard of Waterguard, only 52% had tried it and only 12% were currently using it (Stockman *et al*., 2007).

The study findings suggest that ceramic filters had the highest likelihood of adoption amongst the five HWT methods based on its very high perceived value for the adoption-related criteria. This is supported by Luoto *et al.* (2011) in a study in Bangladesh that the filter had the highest rate of adoption of the four HWT methods they assessed. The four methods were the same as those assessed in this study, except for boiling. However, the filter's comparatively lower scores for some of the compliance-related indicators were found to reduce the likelihood of sustained use (Table 4.13) as well as compliance (Figure 4.9). Brown *et al.* (2009) also noted a decline in filter use of approximately 2% per month after the intervention. The perception of the IG that ceramic filters are low value products because of their cost and the difficulty in accessing them are examples of compliance-related criteria that may affect the user's movement from the adoption to the sustained use stage. This is consistent with the observation by Clasen *et al.* (2004) in a study in Bolivia, that though users had been given the filters free of charge, they said they would only be willing to pay $9.25, even though they thought it cost $24. The perception of the IG that it was difficult to access ceramic filter materials again agrees with the observations by Brown *et al.* (2009) who noted that breakage was a major reason for its declining use.

Lantange *et al.* (2009) contested the report by Sobsey *et al*. (2008), that ceramic filters had the highest potential for sustained use among the HWT technologies they reviewed (hypochlorite based methods, ceramic filters and SODIS). This study supports the findings of Sobsey *et al.* (2008), because the ceramic filters were regarded as a product of high value by the IG, with potential for sustained use i.e. if the product gaps perceived by the respondents were addressed.

Given that Aquatab had a high perceived value in both the IG (75%) and CG (68%) for adoption-related determinants, it is expected to have a high rate of adoption in a real-world context. However, its low perceived value in terms of correct use and users liking its cost and ease of accessing materials would impede adopters' movement to the next stage of sustained use. This study found that the likelihood of adoption in the CG was 'likely' but the likelihood of sustained use reduced to 'fairly likely'. This is consistent with Sobsey *et al.'s* (2008) observations that technologies which depend on a constant purchase of the product are unlikely to achieve sustained use. If these kind of problems are addressed, the likelihood of adoption and compliance would increase, as the study communities perceive Aquatab as a product of fairly high (CG) to high value (IG).

Although PUR was perceived as a high value product by both the IG and CG in terms of its likelihood of adoption, the likelihood of compliance will be impeded by the very low (CG) and low perceived value (IG) attributed to it for correct use, as well as its cost, time taken to treat water and the ease of accessing materials for it. This results in PUR having the lowest likelihood amongst the promoted methods for sustained use (Figure 4.9). This is consistent with the observation by Luoto *et al.* (2011) that of the four HWT methods they assessed, PUR had the lowest usage. This study's reasons for the low perceived value and likelihood of sustained use are consistent with Sobsey *et al.* (2009) that the addition of another step for filtration and the cost of daily purchase of HWT consumables would negatively affect the sustained use of PUR.

Boiling had the lowest perceived value for adoption in both the IG and CG, it had a very low perceived value for correct use, for cost, time taken and ease of accessing materials. This was consistent with findings by Luby *et al.* (1999) that only 20% of boiled water samples and 38% of boiled and filtered water samples were free from contamination. In a study in Guatemala, Rosa *et al.* (2010) also observed that, though boiling improved water quality, only 10.7% of water samples from the self-reported boilers fell within the WHO low-risk category of 1–10 TTC/100 ml. Boiling also had the lowest likelihood of adoption among the assessed HWT methods in both intervention and control groups.

4.5 Conclusion

The intervention and control study communities attached a perceived high value to the HWT methods they had heard about in terms of the adoption-related criteria, ranging from fairly high to highly likely in the intervention group, and between fairly high to likely in the control group. The likelihood of progression from adoption to compliance might be hindered in both groups by the lower perceived value they attached to some of the key indicators of compliance. For example, the likelihood of compliance based on specific indicators such as correct use and user likes for both groups ranged from unlikely to highly unlikely.

The similarities between the two study groups in perceived value about time taken, access to the technology, ease of use, suggest that the method of promotion of HWT into the intervention communities had not enhanced the users' compliance with HWT. The low likelihood of compliance coupled with the observation that the women who were mainly responsible for keeping water in these households were poorly educated, also suggests that the HWT methods cannot be used effectively in these and similar communities. This study identified aspects of the technologies to which users attach low value and those of high perceived value. This information can be used by the sector to review the technologies and also to plan HWT education programs.

5 DETERMINATION OF WATER QUALITY CHANGES BETWEEN SOURCE AND POINT-OF-USE

5.1 Introduction

The findings of Chapters Three and Four indicated that the study communities have inadequate safe water and sanitation, and have attitudes and knowledge gaps that might negatively affect their ability to use household water treatment technologies (HWT) effectively. It was therefore important to assess the quality of water available to these communities and examine the changes in microbiogical quality that take place as people collect and store water. This provides insight into the effectiveness of HWT technologies by providing evidence of the need or otherwise for HWT in the study communities and the effect of users' KAP on drinking water quality at the point-of-use. The chapter also alerts the reader to the additional question of source water chemistry in relation to household water treatment.

In order to meet the health objective of water supply provision, drinking water quality and quantity must be managed in a manner that ensures that the water provided meets the recommended guidelines from collection to the point-of-consumption (Cairncross and Valdamanis, 2004; Schutte, 2006)

There is a school of thought that views as counterproductive the use of decentralised sources as a major strategy for providing drinking water to rural African communities ((Iyer *et al.,* 2006) because of the potential deterioration in microbiological quality from the source to the point-of-use (Mintz *et al.,* 2001, Wright *et al.,* 2004; Zwane and Kremer, 2007).

Other authors do not question the use of decentralised water supply technologies as a major strategy because they argue that piped water supplies may also become contaminated (Younes and Bartram , 2001; Moe and Rheingans, 2006). Others argue that many more external factors affect a non-reticulated system Clasen *et al.,* 2007b) in the process of collecting, transporting and storing water outside the home (Mintz *et al*., 2001; Roberts *et al.,* 2001; Clasen and Bastable, 2003; Wright *et al*., 2004; Levy *et al*., 2008);

The WHO Drinking Water Quality guidelines or their context-specific adaptations are used by countries world-wide to assess the safety of drinking water quality (Fawell and Nieuwenhuijsen, 2003). Authors such as Gundry *et al*. (2006) question the rationale of the equivalent use of the terms ‘improved’ and ‘safe’, pointing out that an improved source does not necessarily mean that it meets the recommended water quality guidelines at the source or at the point-of-consumption.

Consequently, the WHO/UNICEF (2011) recommends household water treatment (HWT) of both improved and unimproved sources, as a short-term protective health measure, if the water is collected from unreliable piped supplies, non-piped supplies outside the home, or unimproved water sources.

Currently, the main focus of household water treatment in rural communities is on the microbiological quality of water with comparatively less attention being paid to the chemical quality of drinking water sources. This disparity is based on the belief of various authors that safeguarding drinking water from microbial contamination by sewage, human or animal excreta is the most important objective of water quality management, even more so than the water’s physical and chemical quality (Enabor, 1998; Clasen and Bastable, 2003; Fawell and Nieuwenhuijsen, 2003; WHO, 2008).

While it is important to address microbiological quality issues, it is also necessary to increase the focus on the chemical quality of drinking water in rural areas, because of the associated long-term health risks of chemicals like arsenic and fluoride and of water treatment products such as aluminium and disinfection by-products such as trihalomethanes and haloacetic acids, and of heavy metals and pesticides (Younes and Bartram, 2001; Fawell and Nieuwenhuijsen, 2003). High quality data on the levels of heavy metals in water and the related morbidity and mortality are therefore necessary (Fawell and Nieuwenhuijsen, 2003), to provide evidence to motivate for includng chemical quality improvement in the design objectives of the household water treatment technologies that are promoted in rural and peri-urban areas.

Given the uncertainty about the quality of the water used by the study communities and the related uncertainty about the ability of decentralised sources to provide potable water to the point-of-use, this study determined the physico-chemical and microbiological quality of the source waters that the households treat, and also determined the changes from the source to the point-of-consumption. In addition, the study determined the stage of contamination and examined the relationship between the knowledge, attitudes and practices identified in the KAP survey and the observed water quality.

5.2 Methods

Water samples were collected in triplicate from household drinking water sources, and from collection and storage containers as previously described by Gundry *et al.* (2006). A questionnaire (Appendix 5.1) was administered to the households at the same time as the water samples were collected in order to identify household-related risk factors that might be associated with water quality deterioriation.

5.2.1 Sampling method

One hundred and seventeen households were selected for sampling from six intervention villages and five control villages (Table 5.1) as described in Chapter Two, Section 2.4.1. Water samples were collected in triplicate, from all 19 water sources used by the households; from their drinking water collection containers as well as from their storage containers. A total of 291 samples were collected and analyzed for physiochemical and bacteriological properties as shown in Table 5.1. The nineteen sources were from: two public stand pipes, two motorized boreholes, one handpump-fitted borehole, three protected handdug wells with handpump, one unprotected handdug well, two rainwater tanks, eight surface water sources.

Table 5.1 Villages tracked from source to the point-of-use in relation to the sample size of the knowledge, attitudes and practices survey.

Village	I or C	Total no. of households in village	KAP survey sample size[a]	Tracking sample size	No. of sources sampled[b]	No. of collection containers sampled	No. of storage containers sampled
Kinasia A lower	I	229	49	16	4	16	16
Kokul A	I	261	55	19	2	19	19
Kabonyo	C	96	20	6	1	6	6
Kombura	C	124	25	8	1	8	8
Akado	I	145	31	10	2	10	10
Angeyoni	I	84	18	5	1	5	5
Kokumu	I	274	62	16	2	16	16
Opuchi	C	41	8	4	1	4	4
Rupia	C	52	13	8	1	8	8
Sigomere	C	51	11	5	2	5	5
Tito	I	37	20	20	2	20	20
Total		1394	312	117	19	117	117

I: intervention village; C: control village; [a]only sample sizes of KAP villages that were tracked are shown; [b] the sources used by the tracked households were sampled and an additional 38 rainwater samples.

5.2.2 Data collection

Following discussions with the heads of the selected communities, unannounced visits were made to the communities in the rainy season from April to May 2010 to sample the sources and household drinking water collection and storage containers and to administer the tracking questionnaire. The respondent was the same as the respondent for the adoption survey i.e. the person in the household responsible for keeping drinking water clean. In order to identify factors that might explain any variability in the observed water quality, the tracking tool assessed certain parameters, some of which were extracted from the previously administered adoption survey questionnaire. The parameters were socio-demographic characteristics, water collection and storage practices, drinking water sources used, water treatment methods and quantity of water consumed by respondent and youngest child (Appendix 5.1).

5.2.3 Experimental procedures

Physico-chemical and microbiological quality of the sources, household and collection containers were determined as earlier described in Sections 2.6.1, 2.6.2 and 2.6.3. The pH, turbidity, electrical conductivity and temperature, and free chlorine residuals of the sources, household collection and storage containers were determined, while the sources were also analysed for chemical parameters such as alkalinity, total hardness, total dissolved solids, total suspended solids, chlorides and nitrates, and heavy metals: aluminium, manganese and lead.

Results were reported according to improvement of sources and not according to intervention and control households, since the the focus of this stage was the determination of water quality.

The relationship between selected KAP factors that may contribute to water quality deterioriation was tested as follows: firstly, a questionnaire with the KAP variables was administered to the 117 households (Appendix 5.1); water samples collected from their storage containers were categorized into those that had acceptable and unacceptable levels of total coliforms and *E. coli*. Water samples with acceptable levels of *E. coli* were those with *E. coli* < 1 cfu/100 ml and unacceptable samples were those ≥ 1 cfu/100 ml (WHO, 2008). Water samples with acceptable levels of total coliforms were those < 10 cfu/100 ml while the unacceptable category were those

≥10 cfu/100 ml (Sphere Project, 2004). Secondly, the 117 households were categorized into active and inactive treaters. The active treaters were those that fufilled three conditions: they self-reported that they used a particular HWT method, and that they had treated their water in the previous seven days, and the interviewers saw their water treatment products,. The inactive treaters were those who self-reported that they treated their water, did not report that they had treated thier water in the previous seven days and interviewers did not see their water treatment products.

5.3 Data analysis

The water quality data was used to provide the results for the three objectives of this stage of the study by:

a) Determining the percentage of samples that were free of total coliforms and *E coli* along the main points of the safe water chain: point of distribution (source), collection point (collection containers), and point-of-use (drinking water storage containers) as previously described by Clasen and Bastable (2003);

b) Determining the arithmetic and geometric means of total coliforms and *E. coli* between the main points of the safe water chain as adapted from Gundry *et al.* (2006);

c) Calculating the difference between the main points of the safe water chain in the the arithmetic and geometric means of total coliforms and *E. coli* and the percentage of samples that were free from total coliforms and *E. coli* as adapted from Gundry *et al.* (2006);

d) Determining p-values using student’s t-tests, with 0.05 taken as the point of significance. Odd ratios were determined at 95% confidence intervals and 5% level of error.

Multivariate analysis was used to test for significant differences between selected KAP variables and the microbiological quality in stored water of both inactive and active treatment households. The difference was considered significant at a p-value below 0.05, at a 95% confidence level. Multivariate analysis was also used to test for the significant difference in stored water quality between the inactive and active treater households in relation to the same selected KAP variables.

5.4 Results

5.4.1 Characterisation of the drinking water sources

Physical water quality

Though the pH and electrical conductivity (EC) of all the drinking water sources fell within the within the recommended WHO (2008) pH guidelines, all water sources exceeded the WHO recommended turbidity level of 0.1 NTU for effective disinfection. The sources however varied in terms of compliance with the aesthetic-based WHO permissible levels of 5 NTU. The public standpipe, the unprotected dug well/handpump-fitted borehole and handpump-fitted dug wells conformed to the guidelines, while the surface water and rainwater sources exceeded the permissible aesthetic value. The surface water had a mean turbidity of 71.75±56.80 NTU and the rainwater a mean turbidity of 23.92±27.46 NTU (Table 5.2).

Chemical water quality

The drinking water quality was satisfactory for all the routine potability parameters, except for nitrates (Table 5.2). All the samples had mean nitrate levels above the 50 mg/l recommended by WHO (2008). The public standpipe had over six times the permissible limits (327.67 mg/l), similar to the handpump-fitted well/boreholes (306.96±211.63 mg/l). The surface water had double the WHO permissible limits (103.86±122.2 mg/l) and the rain water about four times more (208.5±169.5 mg/l).

Heavy metals

Table 5.3 shows the minimum, maximum and mean values of lead, manganese and aluminium in the drinking water sources used by the households. Of the improved water sources, only the handpump-fitted boreholes (75% of those tested) had detectable levels of lead, while lead was not detected in any of the motorized boreholes, public standpipes, unprotected handdug wells or rain water Only the surface water sources exceeded the WHO (2008) guideline values of 0.4 mg/l (Table 5.3).

Table 5.2 Physico-chemical characteristics of water sources used by study households.

Physical parameters

Source type and number	pH; MAL: 6.5 - 8.5				EC µs/cm; MAL: 1000				Temperature ^{0}C				Turbidity (NTU); MAL : 0.1 NTU			
	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev
Surface water (6)	7.87	***9***	8.39	0.45	36	382.33	236.42	150.91	20.67	30	25.68	3.32	***4.5***	***170***	***71.75***	56.86
Rainwater (2)	6.87	8.17	7.52	0.92	10.33	631.67	321.00	439.35	24.50	31.17	27.84	4.72	***4.50***	***43.33***	***23.92***	27.46
UPDW (1)			6.87				***1 376***				25.23				***4.50***	
PDW HP (3)	6.69	7.4	7.05	0.36	412.67	966.00	597.11	319.47	25.80	26.87	26.27	0.55	***4.50***	***4.50***	***4.50***	0.00
Public SP (1)			6.53				126.00				24.23				***4.50***	

Chemical parameters

Source type and number	Total hardness (mg/l) as $CaCO_3$ MAL :				*TDS (mg/l) ; MAL: 1000				Alkalinity (mg/l)				TSS (mg/l)			
	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev
Surface water (6)	12.33	130	48.36	65.72	37.33	387.33	241.45	130.17	40	186.67	136.47	54.95	15.33	690	228.61	264.21
Rainwater (2)	24.67	60.67	42.67	25.46	212	223.33	217.67	8.01	22.67	88	55.33	46.2	17.33	163.33	90.33	103.24
UPDW (1)			34				130				20.67				12.67	
PDW HP (3)	16.20	88.37	63.53	41.01	307.33	548	401.56	128.55	86.07	491.33	221.81	233.42	6	21.33	13.55	7.67
Public SP (1)			397.33				419.33				478.67				17.33	

Chemical parameters contd.

Source type and number	Chlorides (mg/l); MAL : 250				Nitrates (mg/l)as NO_3; MAL: 50			
	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev
Surface water (6)	12.67	37.33	24.11	9.72	18.16	***323.33***	***103.86***	122.2
Rainwater (2)	25.33	34.67	30	6.6	***88.33***	***328.67***	***208.5***	169.95
UPDW (1)			36.67				***15***	
PDW HP (3)	7.33	53.33	33.55	23.67	***62.88***	***439.45***	***306.96***	211.63
Public SP (1)			68.67				***327.67***	

MAL: Maximum allowable limits (WHO, 2008); numbers in bold and italics exceed maximum allowable limits; Public SP (public standpipe); PDWHP; protected dug well with handpump; UPDW: unprotected dug well. *The palatability of water with a TDS level of less than 600 mg/l is good; but increases in unpalatability at TDS levels greater than 1 000 mg/l (WHO, 2008).

Table 5.3 Summary of heavy metal characteristics of water sources used by study households.

Source type and number of sources	**Pb (mg/l); MAL: 0.01**				**Al (mg/l); MAL: 0.2**				**Mn (mg/l); MAL: 0.4**			
	min	max	mean	Std Dev	min	max	mean	Std Dev	min	max	mean	Std Dev
Stream (6)	0.00	***0.49***	***0.12***	***0.19***	0.00	17.59	***10.15***	***5.82***	0.00	1.53	0.57	0.60
dam (2)	0.18	***0.18***	***0.18***	***0.00***	15.44	27.36	***21.40***	***8.43***	0.06	0.24	0.15	0.13
Rain water (1)	0.00	0.00	0.00	N/A	0.00	1.04	***1.04***	N/A	0.00	0.00	0.00	N/A
Unprotected dug well (1)	0.00	0.00	0.00	N/A	0.00	0.00	0.00	N/A	0.45	0.45	0.45	N/A
Protected dug well HP (1)	0.00	0.00	0.00	N/A	0.00	0.07	0.07	N/A	0.00	0.00	0.00	N/A
HP BH (4)	0.00	0.22	0.08	0.09	0.00	2.70	1.32	1.23	0.00	0.12	0.05	0.06
MBH (2)	0.00	0.00	0.00	0.00	0.00	0.21	0.11	0.15	0.00	0.00	0.00	0.00
Public stand pipe (2)	0.00	0.00	0.00	0.00	0.00	0.96	0.48	0.68	0.00	0.11	0.06	0.08

HP:Handpump; MBH: Motorised borehole;HPBH: Handpump borehole; MAL: Maximum allowable Limit; numbers in bold and italics exceed maximum allowable limits.

Microbiological water quality

The improved and unimproved sources were of poor microbiological quality and both categories exceeded the Sphere Project (2004) guidelines of < 10 cfu/100 ml for total coliforms and the WHO (2008) limit of < 1 cfu/100 ml for *E. coli* (Appendix 5.2).The improved sources had a lower geometric mean *E. coli* and total coliform count than the unimproved sources (Figures 5.1 and 5.2). For example, the geometric mean total coliform load was 936.29±987.88 cfu/100 ml and 5 672.42±4 748.69 cfu/100 ml for the improved and unimproved drinking water sources respectively, while the geometric mean *E. coli* load was 5.71±8.69 cfu/100 ml and 296.67±129.35 cfu/100 ml for the improved and unimproved sources respectively.

Though WHO/UNICEF JMP classified the rainwater sources as improved, they had total coliform and *E. coli* loads above the WHO recommended guidelines (Appendix 5.3). Figures 5.1 and 5.2 show that the *E. coli* and total coliform counts of rainwater are extremes and outliers when compared to the other improved sources.

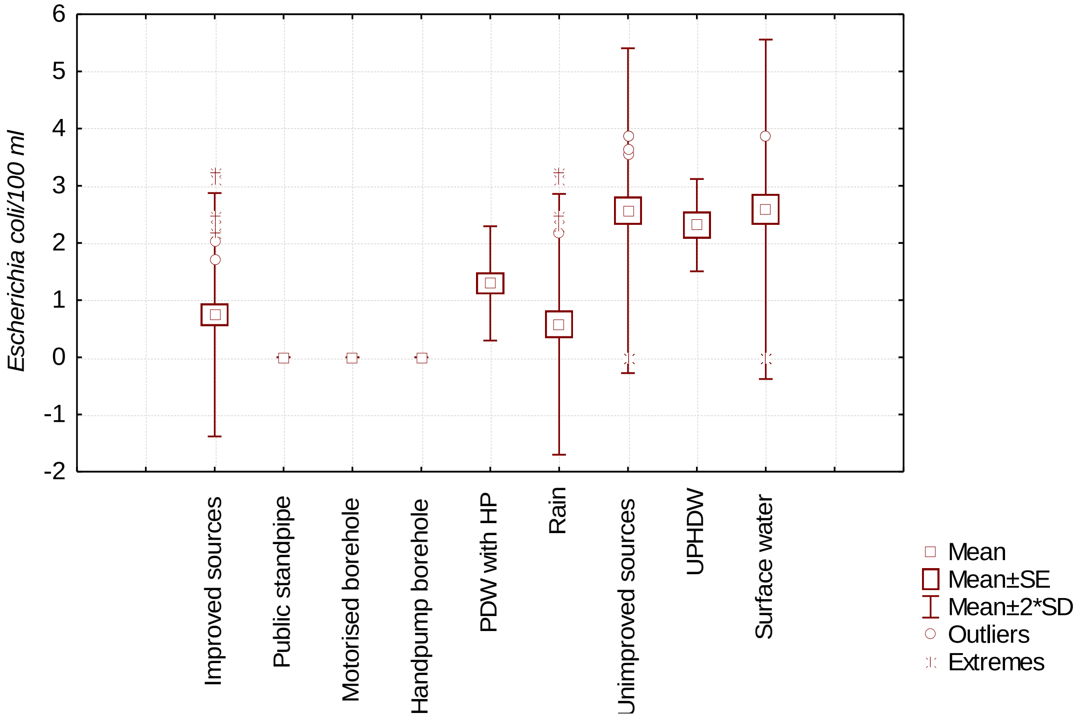


Figure 5.1 Microbiological quality of drinking water sources used by the households using *Escherichia coli* as indicator.

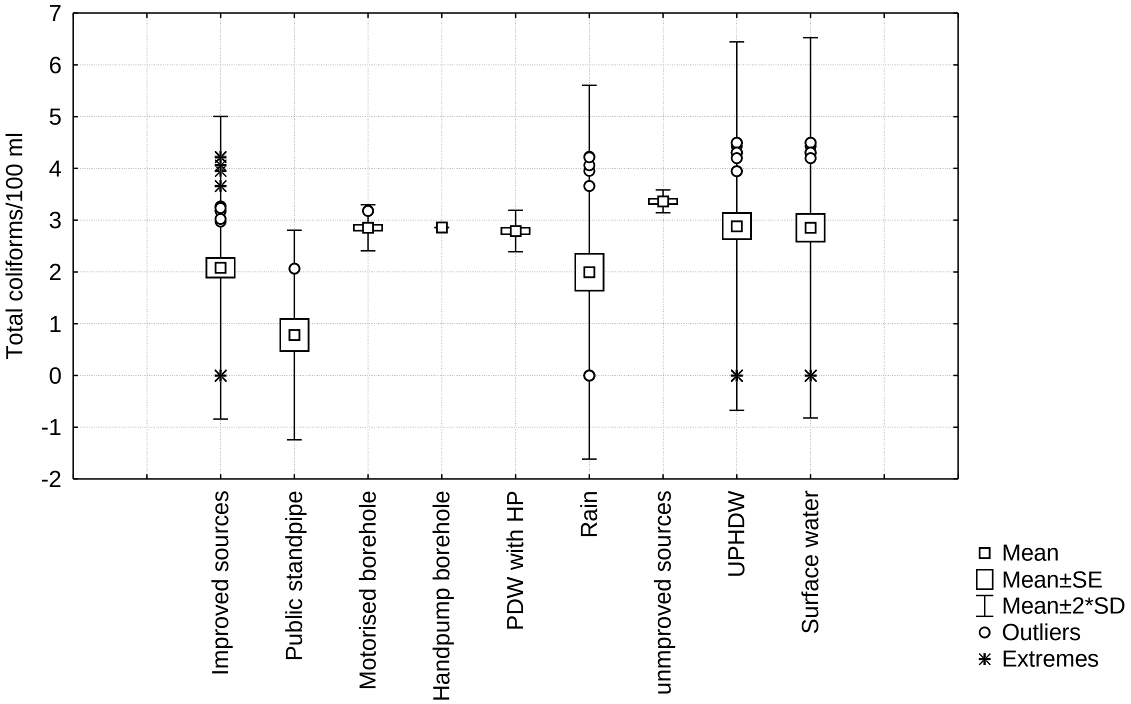


Figure 5.2 Microbiological quality of drinking water sources used by households (total coliforms)

5.4.2 The determination of microbiological water quality changes and stage of highest contamination along the safe water chain

A higher percentage of samples from improved sources than those from unimproved sources complied with the drinking water quality guidelines for total coliform (Sphere Project, 2004) and *E. coli* (WHO, 2008) at all stages of assesment (Figure 5.3). For example, using *E. coli*/100 ml as an indicator, 81.82%, 59.15% and 70.42% of the improved source category, complied at source, collection and storage points respectively, compared to 20.59%, 17.78% and 37.78% of the unimproved respectively.

Of the rainwater samples, 64.29% were within the acceptable *E. coli* limits, while none fell within the acceptable total coliform limits at source (Figure 5.4)

The difference between the improved and unimproved sources in the proportion of samples which had acceptable levels of *E. coli* at all stages was statistically significant with the improved sources being more likely to be free from *E. coli* contamination at source $p < 0.001$; OR: 17.36; 95% CI: 5.6–53.76); collection ($p < 0.0001$; OR: 6.7; 95% CI: 2.73–16.46) and storage points ($p = 0.004$; OR: 4.06; 95%: 1.85–8.92). The samples from the improved sources also had a lower geometric mean load than those from the unimproved sources for both total coliform and *E. coli* at all stages of assesment.

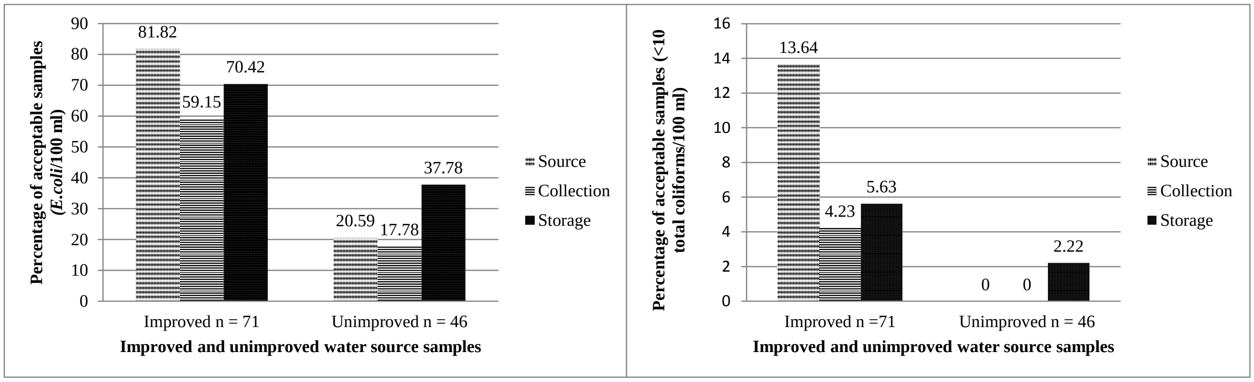


Figure 5.3 Percentage of water sources used by households with acceptable total coliform and *Escherichia coli* levels at source, collection and storage points

TC: total coliform; *E. coli: Escherichia coli*; Acceptable level for *E. coli* = < 1 cfu/100 ml; Acceptable level for total coliform = < 10 cfu/100 ml ; n: number of samples

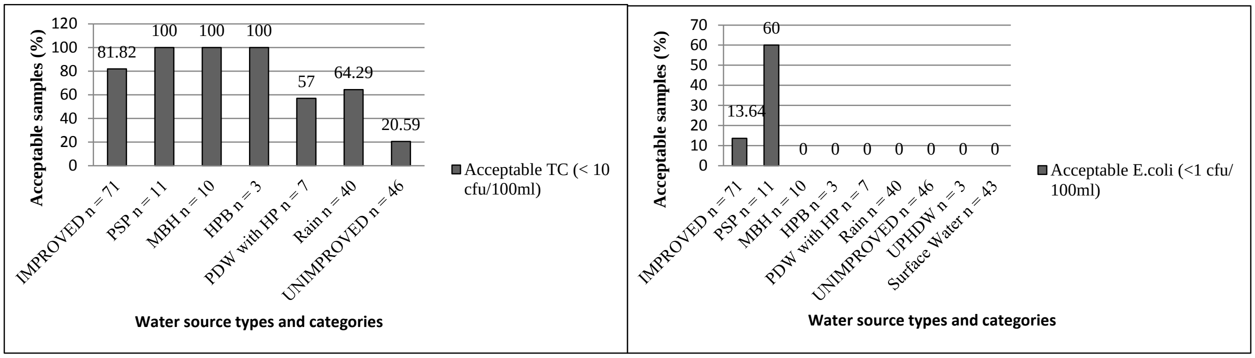


Figure 5.4 Percentage of samples that had acceptable levels of total coliform and *Escherichia coli* at source according to source types.

TC: total coliform; *E. coli*: *Escherichia coli;* Acceptable level for *E. coli* = < 1 cfu/100 ml; Acceptable level for total coliform = < 10 cfu/100 ml . n: number of samples; Improved source (PSP: public stand pipe; MBH: motorised borehole; HPB: handpump borehole; PDW with HP: protected dug well with handpump; rain). Unimproved sources (UPHDW: unprotected handdug well: surface water)

The lowest point of contamination for both total coliforms and *E. coli* was between collection and storage (B1) for both improved and unimproved sources, as shown by the level of increase in the percentage of samples with acceptable levels of *E. coli* (20% in unimproved) and total coliform at this stage (2.22% for unimproved: Figures 5.5 and 5.6).

The stage of greatest contamination with *E. coli*/100 ml was between the source and collection points (A1) for both improved (-22.67% difference) and unimproved sources (-2.81% difference) (Figure 5.5). This finding is reinforced by the observation that the samples from the collection containers were less likely to have acceptable levels of *E. coli* in comparison with the samples from the storage containers (p = 0.02; OR: 0.54; 95% CI: 0.32–0.91) (Table 5.4).

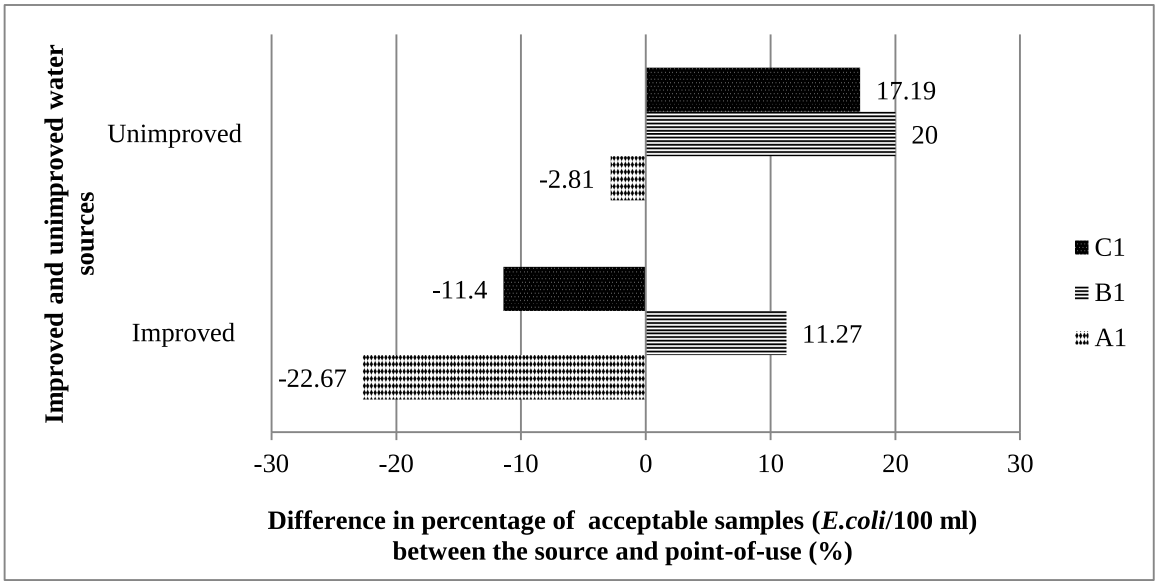


Figure 5.5 Difference in percentage of samples that had acceptable levels of *Escherichia coli* between the source and point-of-use.

Difference: the percentage of acceptable samples at 2nd point minus percentage of acceptable samples at 1st point. Positive numbers indicate a decrease and negative figures indicates an increase; A1: between source and collection; B1: between collection and storage; C1: between source and storage

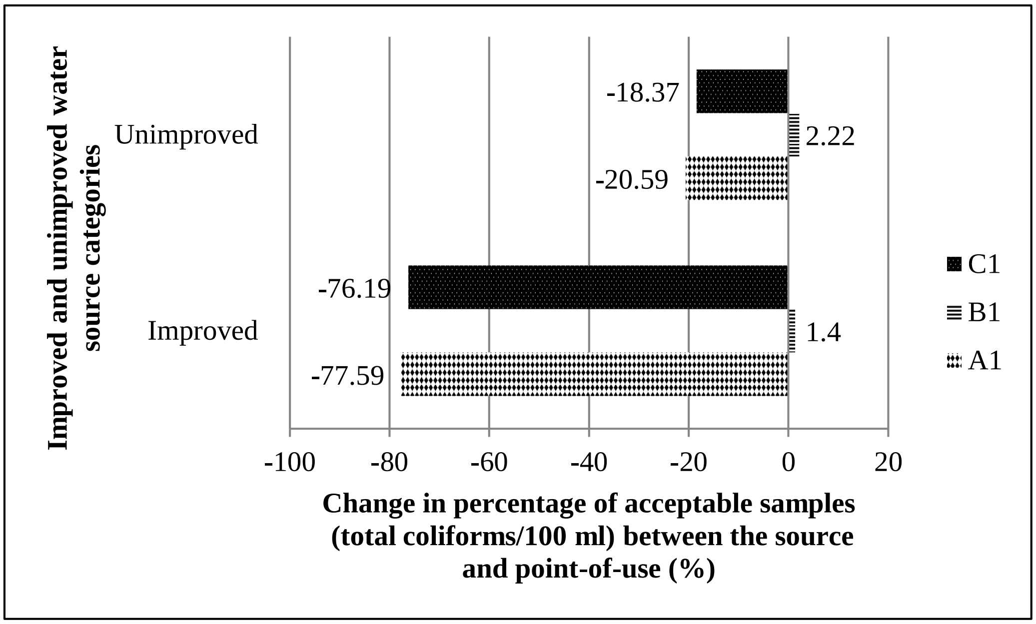


Figure 5.6 Difference in percentage of samples that had acceptable levels of total coliforms between the source and point-of-use.

Difference: the percentage of acceptable samples at 2nd point minus percentage of acceptable samples at 1st point. Positive numbers indicate a decrease and negative figures indicates an increase; A1: between source and collection; B1: between collection and storage; C1: between source and storage

The geometric mean *E. coli* and total coliform also confirm that the greatest contamination in improved and unimproved sources occurs occurs between source and collection, while the lowest contamination occurs between collection and storage (Table 5.5). For example there was a reduction in geometric mean total coliform of -360.34 between this stage, compared with a reduction of -247.78 between source and collection (Table 5.5).

Table 5.4 Test of significance of difference between water handling points in the percentage of samples with acceptable levels of E*scherichia*. *coli* and total coliforms.

Outcome	**Characteristic**				
	Stage	p-value	OR	95% CI	Significance
Acceptable *Escherichia coli* levels	Between source and collection	0.1381	0.64	0.356–1.15	NS
	Between source and storage	0.5561	0.84	0.47–1.5	N.S
	Between collection and storage	***0.02***	***0.54***	***0.32–0.91***	***S***
Acceptable total coliforms	Between source and collection	0.09	0.32	0.08–1.30	NS
	Between source and storage	0.31	1.87	0.55–6.36	NS
	Between collection and storage	0.47	0.59	0.14–2.53	NS

OR: Odds ratio; 95% CI: 95% confidence interval; N.S: Not Significant; S: significant: bold and italics denotes statistical significance if p-value < 0.05 at 95% confidence.

Table 5.5 Difference in geometric means between main points of safe water chain.

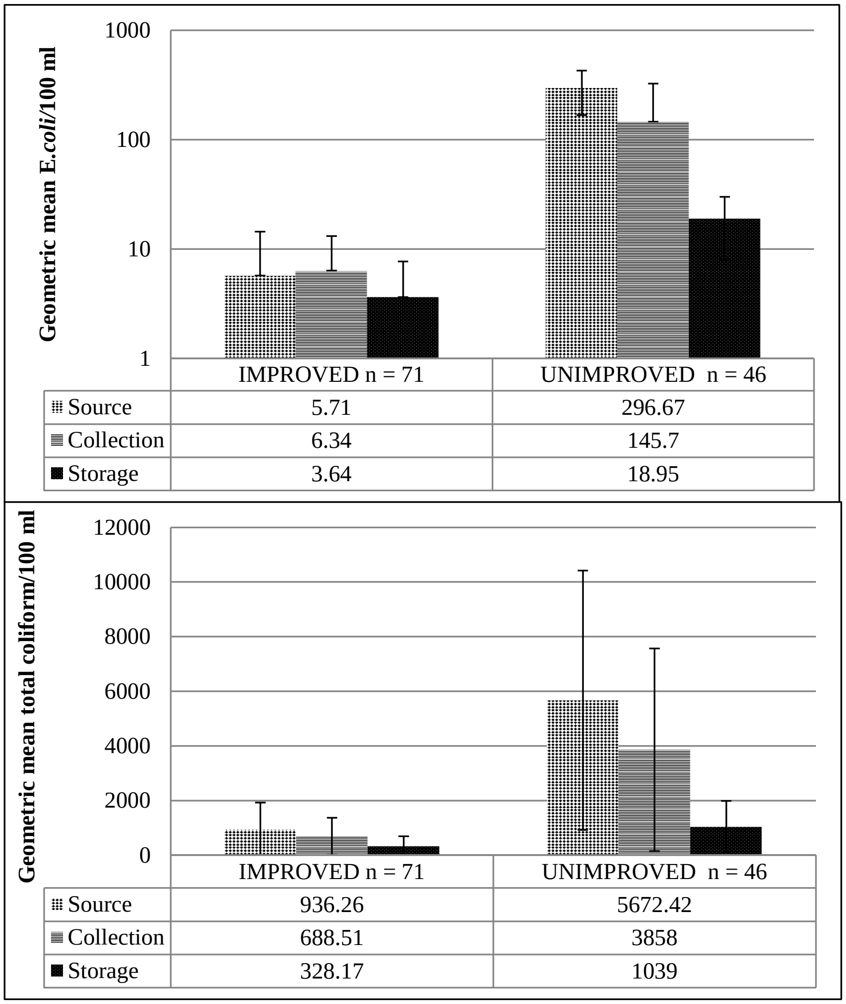
Source category	**Difference in geometric mean *(E. coli)***			**Difference in geometric mean (total coliform)**		
	Between source and collection	Between collection and storage	Between source and storage	Between source and collection	Between collection and storage	Between source and storage
Improved sources	0.63	-2.7	-2.07	-247.78	-360.34	-608.12
Unimproved sources	-150.97	-126.75	-277.72	-1814	-2 819.00	-463

Negative figures indicate a decrease in geometric mean between points (improvement in quality); positive figures indicate an increase in geometric mean between points (decrease in quality).

The pattern of change in microbiological quality differed between the two source categories. The improved source category and individual improved source types (Appendix 5.3) decreased in microbial quality (*E. coli* as indicator) between source and collection, as observed by the changes in the percentage of acceptable samples (Figure 5.3) and geometric means (Figure 5.7).

The unimproved category, however, increased in microbial quality (using *E. coli* as indicator) between source and collection, though both categories improved in quality between collection and storage (Figure 5.7).

When total coliforms were used as the indicator, the pattern of deterioriation was the same for both improved and unimproved souce categories.



	IMPROVED n = 71	UNIMPROVED n = 46
▦ Source	5.71	296.67
▤ Collection	6.34	145.7
■ Storage	3.64	18.95

	IMPROVED n = 71	UNIMPROVED n = 46
▦ Source	936.26	5672.42
▤ Collection	688.51	3858
■ Storage	328.17	1039

Figure 5.7 Geometric mean *Escherichia coli* and total coliform/100 ml at source, collection and storage points.

Household water treatment and observed water quality

The active treater households had a higher percentage of samples that complied with WHO water quality guidelines for *E. coli* than inactive treater households in both improved and unimproved source categories (Figure 5.8). In inactive treater households, 65% of storage container water samples from the improved sources complied with the WHO guidelines in comparison to 72% of the stored water samples in the active treater households. However the differences were not statistically significant (Table 5.6).

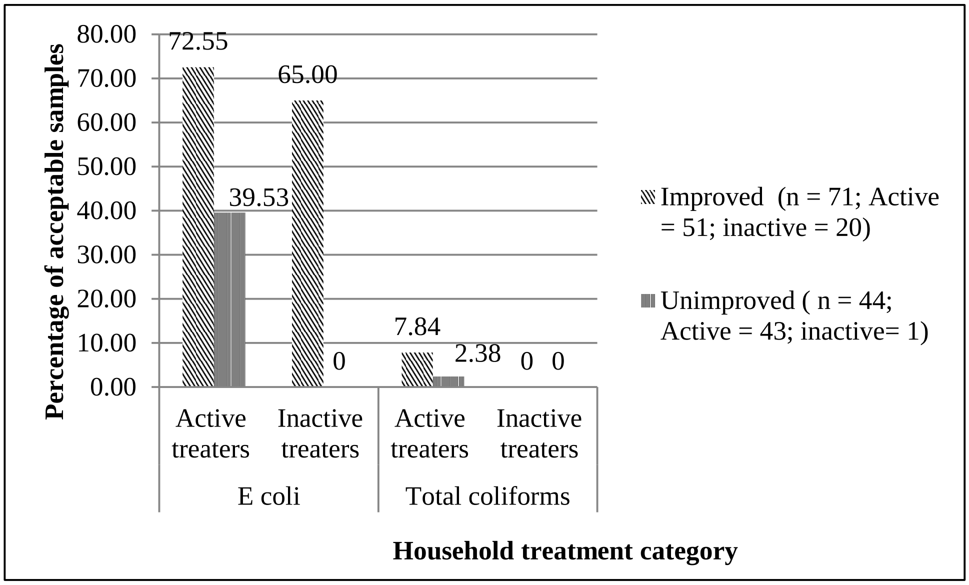


Figure 5.8 Percentage of storage container samples with acceptable levels of *E. coli*/100 ml and total coliforms/100 ml.

Table 5.6 Test of significance of difference in acceptable levels of *E. coli* and total coliforms between active and non-active treatment households.

Outcome	**Characteristic**	**Test**			
		p-value	OR	95% CI	Significance
Acceptable *E. coli* levels between active and inactive treaters	At source	0.12	0.4	0.13–1.29	NS
	At storage	0.71	0.83	0.31–2.19	NS
Acceptable total coliform levels between active and inactive treaters	At source	0.00	0.04	0.04–0.39	S
	At storage	0.28	N/A	N/A	NS

5.4.3 Knowledge, attitudes and practices of study communities as predictors of stored water quality

Relationship between water, sanitation and hygiene knowledge, attitudes and practices and the microbiological quality (E. coli as indicator) of water in storage containers; by active and inactive treater households

The category of drinking water source was positively associated with the quality of the stored water samples in inactive treater households. Those who used improved water sources were significantly more likely to have a higher percentage of samples that complied with the WHO drinking water guidelines for *E. coli* than those who used unimproved sources ($p < 0.02$). Table 5.7 shows that 64.8% of stored samples from improved sources had acceptable *E. coli* levels in comparison to 41.5% of stored samples from unimproved sources used by inactive treater households. The relationship amongst active treater households could not be determined as no active treater household used improved sources.

Table 5.7 shows that neither the statistical test nor the percentages of acceptable samples (*E. coli/*100 ml) amongst inactive and active households suggested a relationship between water quality and category of sanitation. Likewise, there seemed to be no association between the education of the water treatment respondent and the quality of the stored water samples.

Concerning the association between hygiene indicators and stored water quality, neither the statistical test, nor the percentages showed a relationship between the stored water quality and possession of a handwashing facility or evidence of soap near the facility, in active or inactive treater households.

The test of the attitudes to sanitation showed that there was no relationship between the households’ views about sharing and owning toilets and the stored water quality in both active and inactive treater households (Table 5.8).

Relationship between under-5 sanitation, household storage practices, and the microbiological quality of water (E. coli indicator) in storage containers of active and inactive treater households

Table 5.8 also shows no relationship between the safety of sanitation practices by children under five years and the microbiological quality of the stored water. The quality of stored water could not be predicted by most of the storage container characteristics: the type of storage pot, having a cover on storage or collection container, or not decanting from collection to storage container. However, among inactive treaters, the use of a container with a narrow mouth for drinking water storage was positively associated with microbiological quality, with a higher percentage of samples complying with the WHO guidelines for *E. coli* in drinking water ($p < 0.04$). All the stored water samples from the active treaters who used these containers had acceptable *E. coli* limits in comparison to half of the samples from inactive treaters who used wide-mouthed containers (Table 5.8).

Table 5.7 Relationship between water, sanitation and hygiene knowledge, attitudes and practices and the quality of water in storage containers of active and inactive treater households.

Characteristic	Total number of samples	Active treater households	Inactive treater households
		Number of samples and (% acceptable)	Number of samples and (% acceptable)
Water source category			
Improved	54	0 (N/A)	54 (64.8)
Unimproved	61	20 (75)	41 (41.5)
Tests of significance		N/A	***p<0.02; OR: 2.6; 95% CI: 1.11 –6.00***
Sanitation category			
Improved	13	6 (100%)	7 (28.6)
Unimproved	102	14 (64.3)	88 (56.8)
Tests of significance		p = 0.09; OR and 95% CI : NA	p = 0.15; OR: 0.30; 95% CI: 0.06–1.65
Education of water treatment respondent			
No education	15	2 (50)	13 (61.6)
Some education	100	18 (77.8)	82 (53.7)
Tests of significance		p = 0.39; OR: 0.29 ; 95% CI : 0.01–13.65	p = 0.60; OR: 1.38; 95% CI: 0.37–5.38
Evidence of soap near HW facility			
Yes	102	20 (75)	82 (51.2)
No	3	0 (0)	3 (66.7)
Tests of significance		N/A	p = 0.09; OR: N/A
Evidence of HW facility			
Yes	102	17 (76.5)	85 (51.8)
No	4	2 (50)	2 (50)
Tests of significance		p = 0.47; OR: 3.25; 95% CI : 0.16–64.60	p = 0.17; OR: N/A
Importance of having toilets			
Yes	101	20 (75)	81 (56.8)
No	14	0 (0)	14 (42.9)
Tests of significance		N/A	p = 0.33; OR: 1.75; 95% CI: 0.56–5.51
Sharing of household toilets			
Yes	14	3 (100)	11 (54.6)
No	101	17 (70.6)	84 (54.8)
Tests of significance		p = 0.28; OR: 0.71; 95% CI: 0.52–0.96	p = 0.99; OR: 1.01; 95% CI : 0.29–3.56

OR: Odds ratio; 95% CI: 95% confidence interval; HW: handwashing facility; acceptable: *E. coli* level < 1 cfu/100 ml. Italics shows statistical significance at $p < 0.05$

Table 5.8 Relationship between under-5 sanitation, household storage practices, and the quality of water.

Characteristic	**Total number of samples**	**Active treater households**	**Inactive treater households**
		Number of samples and (% acceptable)	Number of samples and (% acceptable)
Safe versus unsafe U5 defecation practices			
Safe	38	14 (85.6)	24 (37.5)
Unsafe	30	5 (60)	25 (56)
Tests of significance		p = 0.27; OR: 4.00; 95% CI:0.39–41.23	p = 0.26; OR: 0.47; 95% CI: 0.15–1.47
safe versus unsafe U5 faecal disposal			
Safe	66	19 (79.0)	47 (48.9)
Unsafe	4	0 (0)	4 (25)
Tests of significance		N/A	p = 0.61; OR: 2.88; 95% CI: 0.28–29.68
Safe versus unsafe disposal of anal cleansing material			
Safe	108	20 (75)	88 (54.6)
Unsafe	6	0 (0)	6 (66.7)
Tests of significance		N/A	p = 0.69; OR: 0.6; 95% CI: 0.10–3.45
Type of storage pot			
CDC vessel	1	0 (0)	1 (0)
Plastic bucket	2	0 (0)	2 (100)
Clay pot	74	5 (60)	69 (46 .4)
Jerry can (Not CDC type)	13	1 (0)	12 (75)
Ceramic filter	14	14 (85.7)	0 (0)
Drum	10	0 (0)	0 (0)
Tests of significance		N/A	N/A
Mouth type of container			
Narrow	5	0 (0)	5 (100)
Wide	90	0 (0)	90 (52.2)
Has tap	18	18 (73.7)	0 (0)
Could not observe	1	1 (100)	0 (0)
Tests of significance		p = 0.55; OR: N/A	***p = 0.04***
Cover on storage container			
Yes	113	20 (75)	93 (53.8)
No	2	0 (0)	2 (100)
Tests of significance		N/A	p = 0.19
Same container for storage and collection			
Yes	112	19 (73.7)	93 (54.8)
No	3	1 (100)	2 (50)
Tests of significance		p = 0.55; OR: N/A	p = 1; OR: 1.21; 95% CI: 0.07–20.0
Importance of collection container cover			
Yes	114	20 (75)	94 (54.3)
No	1	0	1 (100)
Tests of significance		N/A	N/A
Collection container covered			
Yes	95	20 (75)	75 (54.7)
No	20	0	20 (56)
Tests of significance		N/A	N/A

HW: handwashing facility; acceptable: *E. coli* level < 1 cfu/100 ml; U5: under-five years old**.**

Relationship between active water treatment and the microbiological quality of water in storage containers

Unlike the findings of the association between the KAP variables and water quality, when the active and inactive treater households were further compared by variable, a strong influence of water treatment on water quality was observed. Of the 38 KAP variables compared, the results showed that for 22 of the variables examined, the active treaters had a higher percentage of samples within acceptable *E. coli* limits than the inactive treaters. Of the remaining 16, 14 variables could not be compared because either the active or inactive treater groups did not have any household within that category, while one of the remaining two variables, which was 'no evidence of handwashing facility', showed the same proportion of acceptable samples in the two groups. The 'no education' variable was the only exception in which the inactive treaters had a higher proportion of acceptable samples (Tables 5.9 and 5.10).

The observed difference in proportion was statistically significant for four of the variables: the use of an unimproved drinking water source, the use of improved sanitation, the practice of safe under-five year defecation and safe disposal of under-five faeces. Table 5.9 shows that active treater households who had safe under-five year defecation had a higher percentage (75%) of acceptable samples than inactive treaters (54.6%) with the same sanitation habits ($p < 0.01$).

Table 5.9 Microbiological quality of stored water samples from active and inactive treatment households stratified by selected water, sanitation and hygiene variables.

Variable	**Total Frequency**	**Active treater**			**Inactive treater**			**p-value**	**OR**	**95% CI**
		Total frequency	Frequency (acceptable)	% (acceptable)	Total frequency	Frequency (acceptable)	% (acceptable)			
Water source category										
Improved	54	0	0	0	54	35	64.81			N/A
Unimproved	61	20	15	75	41	17	41.46	***0.02***	***4.24***	***1.29 –13.89***
Sanitation category										
Improved	13	6	6	100	7	2	28.57	***0.02***		***N/A***
Unimproved	102	14	9	64.29	88	50	56.82	0.77	1.37	0.42–4.42
Education of HWT survey respondent										
No education	15	2	1	50	13	8	61.54	1.00	0.63	0.031–12.41
Some education	100	18	14	77.78	82	44	53.66	0.07	3.02	0.92–9.97
Evidence of HW facility										
Yes	102	17	13	76.47	85	44	51.76	0.11	3.03	3.03–10.04
No	4	2	1	50	2	1	50	1.00	1.00	0.02–50.40
Evidence of soap near HW facility										
Yes	102	20	15	75	82	42	51.22	0.08	2.86	0.95–8.59
No	3	0	0	0	3	2	66.67			N/A
Importance of having toilets										
Yes	101	20	15	75	81	46	56.79	0.20	2.28	0.76–6.88
No	14	0	0	0	14	6	42.86			N/A
Sharing of household toilets										
Yes	14	3	3	100	11	6	54.55	0.26		N/A
No	101	17	12	70.59	84	46	54.76	0.29	1.98	0.64–6.13

OR: Odds ratio; 95% CI: 95% confidence interval; HW: handwashing facility; acceptable: *E. coli* level < 1 cfu/100 ml; U5: under five years old; Italicised p values denotes statistical significance: $p < 0.05$

Table 5.10 Microbiological quality of stored water samples stratified by household storage and under-five sanitation practices.

Variable	Total frequency	Active treater			Inactive treater			p-value	OR	95% CI
		Total frequency	Frequency (acceptable)	% (acceptable)	Total frequency	Frequency (acceptable)	% (acceptable)			
Safe versus unsafe U5 defecation practices										
Safe	38	14	12	85.71	24	9	37.50	***0.01***	***10***	***1.81–55.29***
Unsafe	30	5	3	60	25	14	56.00	1.00	1.179	0.17 - 8.33
safe versus unsafe U5 faecal disposal										
Safe	66	19	15	78.95	47	23	48.94	***0.03***	***0.26***	***0.07 –0.89***
Unsafe	4	0	0	0	4	1	25.00	N/A	N/A	N/A
Safe versus unsafe anal cleansing material disposal										
Safe	108	20	15	75	88	48	54.55	0.13	2.50	0.84–7.48
Unsafe	6	0	0	0	6	4	66.70	N/A	N/A	N/A
Type of storage pot										
CDC vessel	1	0	0	0	1	0	0.00	N/A	N/A	N/A
Plastic bucket	2	0	0	0	2	2	100.00	N/A	N/A	N/A
Clay pot	74	5	3	60	69	32	46.38	N/A	N/A	N/A
Jerry can (Not CDC type)	13	1	0	0	12	9	75.00	N/A	N/A	N/A
Ceramic filter	14	14		0	0	0		N/A	N/A	N/A
Drum	10	0	0	0	10	0	0.00	N/A	N/A	N/A

OR: Odds ratio; 95% CI: 95% confidence interval; HW: handwashing facility; acceptable: *E. coli* level < 1 cfu/100 ml; U5: under five years old; Italicised p values denotes statistical significance: $p < 0.05$

Table 5.10 contd. Microbiological quality of stored water samples stratified by household storage and under-five sanitation practices.

Variable	**Total frequency**	**Active treater**			**Inactive treater**			**p-value**	**OR**	**95% CI**
		Total frequency	Frequency (acceptable)	% (acceptable)	Total frequency	Frequency (acceptable)	% (acceptable)			
Mouth type of container										
Narrow	5	0	0	0	5	5	100.00	N/A	N/A	N/A
Wide	90	0	0	0	90	47	52.20	N/A	N/A	N/A
Has tap	18	18			0			N/A	N/A	N/A
Could not observe	1	1	1	100	0	0	0.00	N/A	N/A	N/A
Cover on storage container										
Yes	113	20	15	75	93	50	53.76	0.13	2.58	0.87–7.68
No	2	2	0	0	2	2	100.00	N/A	N/A	N/A
Same container for storage and collection										
Yes	112	19	14	73.68	93	51	58.84	0.20	2.31	0.77–6.93
No	3	1	1	100	2	1	50.00	N/A	N/A	N/A
Collection container cover important										
Yes	114	20	15	75	94	51	54.26	0.13	2.5294	0.85–7.53
No	1	0	0	0	1	1	100.00	N/A	N/A	N/A
Collection container covered										
Yes	95	20	15	75	75	41	54.67	0.13	2.49	0.82–7.55
No	20	0	0	0	20	11	56.00	N/A	N/A	N/A

5.5 Discussion

5.5.1 Characterisation of water sources

This study noted levels of turbidity above the WHO recommended guidelines in all the drinking water sources sampled, including rainwater. This suggests that the effectiveness of household water treatment may be reduced. This is especially true for the chlorine-based water treatment methods which are affected by turbidity (Sobsey *et al*., 2008; WHO, 2008). This study's finding is consistent with studies in Western Kenya and other parts of Africa. For example in Western Kenya, Crump *et al.* (2004) reported a range of 0.3–1 724 NTU and Albert *et al*. (2010) noted a mean turbidity of 132 NTU in surface water drinking water sources. In a study of small water treatment plants in two provinces in South Africa, Obi *et al*. (2007) observed that the mean turbidity levels of treated water at the point-of-use exceeded international guidelines.

The effectiveness of HWT technologies may also be reduced by the inability of the users to select HWT methods appropriate for treating highly turbid water sources. For instance, PUR was used by 9.3% in the intervention group and no households in the control group while ceramic filters were used by only 23.26% in the IG and no household in the CG (Appendix 4.3). This is consistent with Albert *et al.* (2010) who observed that contrary to expectations, households which used surface water sources did not use PUR more than Waterguard, even though Waterguard has been shown to be ineffective in highly turbid waters (Crump *et al*., 2004 and Lantagne, 2006)

The study found excessive levels of some of the assessed chemical parameters in the drinking water sources used by the study communities. For example, the study found that all the drinking water sources analyzed had mean nitrate levels above those recommended by WHO (2008) (Table 5.2). This is consistent with the findings by Rossiter *et al.* (2010) in Ghana where 21% of the samples from the improved sources exceeded the WHO (2008) guideline levels for nitrates and some of the samples were found to be eight times higher than the acceptable limits. Though nitrates have no direct effect on health, they are a concern because they are associated with agricultural chemicals, particularly in developing countries where famers apply them without the necessary knowledge or government regulation (Peter-Varbanets *et al*., 2009).

Excessive levels of lead were also found in samples from both the unimproved and improved drinking water sources used by the study communities (Table 5.3). For example, 60% of the surface water samples and 75% of the samples from the handpump-fitted boreholes used by the study households exceeded the WHO guideline limit of 0.01 mg/l. Rositter *et al*. (2010) in Ghana and Okonkwo and Mothiba (2005) in South Africa also reported excessive levels of lead in drinking water sources.

Twenty five percent of the surface water sources exceeded the WHO (2008) guideline values of 0.4 mg/l for manganese (Table 5.3), an amount higher than the 11.6% found by Rossiter *et al.* (2010) but lower than the 85% in drinking water sources in northern Nigeria observed by Onabolu *et al*. (2011). WHO (2008) noted that the neurological effects of exposure to high manganese levels have been proved only through inhalation in an occupational setting and not from drinking water. However aesthetic effects of high levels of manganese cause consumers to reject improved water sources for less microbiologically safe but non-deposit forming sources (WHO, 2008; Rossiter *et al*., 2010). These findings are significant for public health as the technologies recommended for removal of these chemicals (Schutte, 2006) are not available to the consumers. Consequently, the sector's position on the objective of HWT in the rural areas exposes these communities and others like them to the health risks associated with excessive levels of aluminium, manganese, lead and nitrates present in their drinking water sources, even if they treat their water with the currently promoted technologies.

All drinking water sources used by the study households exceeded the Sphere Project (2004) recommended total coliform guideline value of 10 cfu/100 ml, underscoring the need for HWT and proper water source development. Improved sources like public standpipes and the motorized and handpump-fitted boreholes conformed to the < 1 cfu/100 ml guideline for *E. coli* (WHO, 2008), which was consistent with Clasen and Bastable's (2003) findings in Liberia that such improved sources were not faecally contaminated. However, this study found that rainwater had the highest *E. coli* load of 8.91±22.35 cfu/100 ml among the improved source samples (Appendix 5.3), and that about 30% and 100% of the rain water samples exceeded the acceptable *E. coli* and total coliform drinking water recommended limits (Figure 5.4). This is consistent with a report by Lantagne *et al.* (2008), who found that the rainwater samples in rural Western Kenya had a higher level of faecal contamination compared to protected wells and a report by

Mbaka *et al.* (2004) in three divisions of Nairobi, Kenya that 49% of samples taken from roof-top harvesting rainwater tanks were faecally contaminated.

This is of concern because the classification of rainwater as an improved source implies that the water is safe for consumption and exposes consumers to the health risks inherent in untreated contaminated rain water. Wright *et al.* (2004) observed that when users have the impression that the quality of their drinking water source is good, they neglect to carry out the necessary activities for protecting water quality. The potential for such risky behaviour was also observed during this study, when the KAP survey results showed that the most frequent reason given by 50% of the intervention and 60% of the control group for neglecting to treat their water in the past two weeks before the study was the perceived safety of rainwater. The study also noted that highly contaminated surface water is the predominant source during the non-rainy season. Such surface water had geometric mean *E. coli* levels of 388.13±30.45 cfu/100 ml. Albert *et al.* (2010) also observed a high level of faecal contamination with *E. coli* in earth pans (700 cfu/100 ml) and river water (602 cfu/100 ml) in Western Kenya, as did Crump *et al.*, 2004 (5 934 cfu/100 ml) also in Western Kenya.

5.5.2 The determination of changes along the water chain

The study results indicate that the microbiological quality of the improved drinking water sources deteriorated after collection as was shown by the decrease in percentage of samples with acceptable levels of *E. coli* (< 1/100 ml) between the source and collection and between source and storage, though there was an increase between collection and storage (Figure 5.3). Such deterioration is consistent with studies by Clasen and Bastable (2003), Wright *et al.* (2004) and Gundry *et al.* (2006), who noted significant deterioration in drinking water quality after collection in settings that ranged from the eastern, western, northern, central and southern parts of Africa, to central and southern America, as well as various parts of Asia.

The observation of a reduction in microbiological quality between the source and storage in the improved sources may at face value provide a basis for the view held by sector practitioners like Peter-Varbanets *et al.* (2009), that the sector should focus efforts on providing household water treatment at the point-of-use, since decentralised improved sources are likely to become contaminated during collection (Peter-Varbanets *et al*., 2009).

However, a closer examination of the study results shows that the improved sources were of better quality than the unimproved sources at all stages of the assessment (Figures 5.3 and 5.7). Furthermore, source improvement was statistically associated with a higher degree of compliance with WHO guidelines for *E. coli* at source, collection and storage. This is consistent with the report by Clasen and Bastable (2003) of a positive association between source improvement and the absence of *E. coli* in Sierra Leone ($p < 0.0001$). Consequently, this study supports the alternative view that household water treatment should be a short-term measure, which should not detract from or absolve the sector or government of the responsibility of providing safe and sustainable water supplies (Clasen, 2010; WHO/UNICEF 2011).

Though samples from improved sources were of better quality than samples from unimproved sources at the three stages of assessment, it is pertinent to point out that the deterioration in microbiological quality was higher in the samples from improved sources (Figure 5.6). This deterioration in improved sources after collection conforms to Wright *et al*. (2004) who noted that the degree of contamination was greater when the source water had a low microbiological load.

The observed deterioration in water quality may be attributed to contact with faecally-contaminated hands after water is collected and stored (Roberts *et al*., 2001; Wright e*t al.,* 2004, Trevett *et al.,* 2005). This is supported by this study's earlier reported KAP survey finding that only 29% and 20% of the intervention and control group respectively washed their hands with water and soap after defecation (Table 3.12). The study findings highlight the importance of integrating hygienic water use behaviour with water supply improvement.

5.5.3 Determination of the stage of highest level of contamination

Determining the highest point of contamination is critical in developing strategies for effective HWT and the results indicate that the highest point of contamination with *E. coli* and total coliforms in improved and unimproved water source categories was between the source and collection points (Figures 5.5 and 5.6 and Table 5.5). The exception to this was *E. coli* contamination in the unimproved water source category. Interestingly, these findings are consistent with two seemingly contradictory observations: the first is made by a number of researchers: Wright *et al.* (2004) who observed that half the 57 studies they reviewed noted a decline in quality after collection and none observed a significant improvement after collection. The second view is that of Levy *et al*. (2008) who, unlike other researchers, found that the source water quality had higher counts of indicator organisms than the control containers at household level. The findings of this study confirm the first view about a decline after collection because, as already shown, the pattern of microbiological quality change suggests that the highest degree of contamination was between source and collection. It is also consistent with the second view by Levy *et al*. (2008) because there was an improvement in quality between collection and storage (Figure 5.3). Therefore, the stage at which the water quality was assessed, and the point of comparison influences the findings about changes in microbiological quality from source to the point-of-use.

A possible effect of water treatment on the water quality is suggested by the observation that degree of improvement in total coliform and *E. coli* load was consistently lower between source and collection than between collection and storage. Furthermore, the greatest improvement coincides with the point at which households that treat water would normally apply water treatment products. This is a reasonable conclusion to draw, since the study results show that only 7.76% of the combined intervention and control communities do not treat water, and it is consistent with the observation by Levy *et al*. (2008) that water treatment was the most important variable for the differences observed in water quality in their own study.

5.5.4 Identification of the knowledge, attitudes and practices that determine observed water quality

The study demonstrated a statistically significant association between two of the 16 assessed KAP variables and the quality of water in the storage containers (Tables 5.7). The first variable was the source water quality in households and the results showed that amongst households that do not treat their water, those households that use improved water sources have a higher percentage of samples that conform to the WHO drinking water guidelines for *E. coli* compared to those households that use unimproved sources. This is consistent with the observations by

Clasen and Bastable (2003) and Gundry *et al.* (2006) that at the point of distribution, water from improved sources is of better quality than water from unimproved sources, and further underscores the importance of providing improved water supply.

The other predictive characteristic was the mouth type of the storage container. The study found that all inactive treater households that had storage containers with narrow mouth types had acceptable levels of *E. coli* in their stored water, while only half of those that had wide mouths had acceptable levels. This finding is consistent with that of Levy *et al.* (2008), who found a significant association when *enterococcus* was used as the index organism but not with *E. coli*.

The inability to detect a statistically significant association between sanitation, education and storage characteristics and household water quality is consistent with studies by other authors (Quick *et al*., 2002; Clasen and Bastable, 2003; Trevett *et al.*, 2004; Levy *et al.*, 2008). This does not prove that there is no association between these KAP characteristics and water quality but rather that more nuanced multiple indicators should be used to detect such relationships. For example, although Clasen and Bastable (2003) as this study, found no relationship between sanitation facilities and the presence of thermotolerant coliforms, Levy *et al.* (2008) were able to show a link between sanitation and water quality using *enterococcus* as the indicator organism.

Authors have asked whether the cases of observed ineffectiveness of these technologies are due to poor user know-how, poor compliance, inefficacy of the technologies or because of the differences between laboratory, field trials and real-world contexts (Dean and Hunter, 2009; McLaughlin *et al.,* 2009). The study findings (Tables 5.9 and 5.10) show that for all but one of the 38 tested variables, active treaters denoted by households that could show their water treatment products, had a consistently lower proportion of faecally contaminated samples than those that could not show their products but self-reported water treatment (inactive treaters). This observation holds true for households that use both improved and unimproved sanitation who use unimproved drinking water sources or have safe and unsafe under-five sanitation practices. When this finding is considered in the light of this study's earlier reported results of poor user knowledge, attitudes and practices and skills (Chapters Three and Four), the results **demonstrate that household water treatment improves microbiological water quality even outside**

laboratory and field trial situations and as a stand-alone and combined intervention in spite of poor user knowledge.

5.6 Conclusion

In view of the chemical contamination observed in rural areas and the ineffectiveness of currently promoted household water treatment technologies in improving the chemical quality of drinking water, the sector needs to re-examine the design objectives of household water treatment technologies for rural and peri-urban communities. Such a review should include chemical water quality improvement in addition to the current objective of microbiological quality treatment.

The study confirms the deterioration in microbiological quality of drinking water sources after collection, underscores the importance of improving access to safe water through improved water supply provision, as well as the need for and importance of household water treatment, even under less than ideal conditions. The study also provides evidence not only of faecal contamination of harvested rainwater samples but also of the risky treatment-related behaviour of the study communities, providing a justification for the reclassification of rainwater and increasing awareness about hygienic harvesting and management of rainwater from source to the point-of-use.

6 ASSESSING THE EFFECTIVENESS OF HOUSEHOLD WATER TREATMENT TECHNOLOGIES

6.1 Introduction

Rural communities are more exposed to the health effects of unsafe drinking water, and need technologies which treat drinking water effectively at the household level to protect them from water-borne diseases (Mintz *et al.*, 2001).

Piped water provision has been suggested as an option for achieving the health benefits of water supply provision (Clasen and Cairncross, 2004; Stevenson, 2008). However, this is considered unfeasible in the short-term because of infrastructure requirements and the prohibitive costs of manpower, supplies, equipment and logistics support (Quick *et al.*, 2002; Clasen and Edmonson, 2005; Peter-Varbanets *et al*., 2009). Household water treatment (HWT) has been suggested as a more cost-effective and appropriate option (Mintz *et al*., 2001; Hutton and Haller, 2004 and Peter-Varbanets *et al*., 2009). For example, Huttton and Haller (2004) estimated the cost of piped water provision/capita/day in Africa as $12.75 compared to $0.33 for HWT.

Some of the HWT methods that have been proven to have microbial efficacy in small scale-trials include point-of-use chlorination, filtration, solar disinfection, boiling, combined flocculant-disinfectant (Clasen and Cairncross, 2004; Sobsey *et al*., 2008; Lantange *et al*., 2009, Peter-Varbanets *et al*., 2009) and the use of natural plant coagulants (Pan African Chemistry Network, 2010). Clasen (2008) estimated that almost 17 million people use HWT technologies. This figure however, represents only a fraction of the 884 million people without access to improved water sources in 2008 (WHO/UNICEF, 2010) because the low-income populations, who form the bulk of those without access, do not typically adopt or sustain HWT (Albert *et al.*, 2010).

Chlorination

Chlorination at the household level can be carried out using variations of hypochlorite-based products such as sodium hypochlorite, calcium hypochlorite, flocculant-disinfectant and sodium dichloroisocyanurate (Clasen and Edmonson, 2005; Clasen *et al.*, 2007a). Though factors such as concentration, contact time, pH of the water, temperature and turbidity determine the effectiveness of chlorination, chlorine can reduce most water-borne pathogens by 4 log reductions at an optimal drinking water pH of 8 and contact time of 30 minutes (Clasen and Edmonson, 2005; WHO, 2008).

Sodium hypochlorite

Sodium hypochlorite has been proven to be microbiologically effective (Luby *et al.*, 2008). In studies in Bangladesh and Bolivia, Sobsey *et al.* (2003) found that an addition of 1–5 mg/l of sodium hypochlorite reduced *E. coli* concentrations in the stored drinking water in intervention (HWT user) households to < 1 cfu/100 ml compared to higher concentrations in control (non-treatment households). Though Sodium hypochlorite has been proved to be microbiologically effective, authors differ in their opinion of its effectiveness. Mintz *et al. (*2001) views sodium hypochlorite as the most appropriate household water treatment method capable of reducing diarrhoeal illness by 85%, but Sobsey *et al. (*2008), in a systematic review spanning eastern and southern Africa, central and southern America, reported an effectiveness of just 37%, and considered it to be the least accepted HWT method with the lowest likelihood of sustained effectiveness. Sodium hypochlorite is not effective against cyst-forming protozoa such as *Cryptosporidium* spp. (CDC, 2012b) and *Giardia lamblia* cysts (Kim *et al.*, 2001) and turbidity reduces the biocidal action of sodium hypochlorite (Crump *et al.*, 2004; Sobsey *et al.*, 2009).

PUR

Some authors consider PUR to be more effective than sodium hypochlorite. In a study in Western Kenya, Crump *et al.* (2004) reported that the flocculant-disinfectant product reduced *E. coli* counts in 97% of water samples from 30 different sources to acceptable levels, compared to the 83% reduction observed in the same samples with sodium hypochlorite treatment. They also observed that flocculant-disinfectant reduced turbidity to < 5 NTU in 87% of the samples compared to 17% with sodium hypochlorite treatment (Crump *et al.*, 2004). Rangel *et al.* (2003) however, found no difference in the two products in terms of microbial reduction after treatment (92%), though like Crump *et al.* (2004) they found a higher reduction in turbidity by PUR (98%) than sodium hypochlorite (45%).

Chlorine Tablets (Sodium Dichloroisocyanurate)

In a study in Bangladesh, Clasen *et al*. (2007a) observed a geometric mean thermotolerant coliform count of 2.8 in the intervention households after treatment with Aquatab in comparison to 604.1 in the control households. Although few studies have been carried out to compare the efficacy of NaDCC with NaOCl, NaDCC is more effective on a variety of microbes such as aerobic mesophiles, moulds, yeasts, total coliforms, *E. coli* and *Salmonella* spp. (Clasen and Edmonson, 2005). This is because of the more gradual release of free available chlorine into the water and its lower pH in dissolution, which favours dissociation into the hypochlorous ion which is more effective than the hypochlorite ion (Clasen and Edmonson, 2005). In a study in Korea, Kim *et al.* (2001) observed that although sodium hypochlorite showed a more rapid initial disinfection of *Giardia lambia* cysts in comparison to NaDCC, the disinfection slowed down after the first 15 minutes contact with 5 and 10 mg/l of sodium hypochlorite, and subsequent disinfection was negligible even after 2 h of contact. In contrast, NaDCC had slower disinfection rates initially but had a lower pH and retained 70–80% of its residual effect even after 3 h, resulting in continuous inactivation of the cysts (Kim *et al.*, 2001).

Ceramic filters

In a study in Bolivia, Clasen *et al.* (2004) observed that all the water samples from the intervention households which used a ceramic filter, were free of thermotolerant coliforms after treatment, compared to 15.5% of the samples from non-user households. du Preez *et al.* (2008) conducted a study in South Africa and Zimbabwe which showed that a higher percentage of samples from user households (56.9%) were free of *E. coli* compared to non-user households (30.2%). This translated into a reduced risk of diarrhoea of 70% and 80% in the Bolivian and combined South African and Zimbabwean studies respectively (Clasen *et al.*, 2004; du Preez *et al.*, 2008).

The effectiveness of household water treatment within a real-world context is critical to safeguarding the health of the 884 million people who lacked access to the use of improved sources in 2008 and others who unknowingly consume contaminated water from improved sources (Luby *et al.*, 2008; WHO/UNICEF, 2011).

In view of the above, it is necessary to evaluate the post-implementation *effectiveness* of HWT technologies in rural households under real-world conditions, rather than their *efficacy* under more controlled situations. Lantagne *et al.* (2009) noted that efficacy has to be examined in conjunction with user preferences as well as the local water quality, which this study has reported on in Chapter Four and Chapter Five respectively. The focus of this chapter is therefore on the microbial performance of the HWT technologies.

6.2 Methods

The study assessed the performance of sodium hypochlorite (branded Waterguard), combined flocculant-disinfectant (branded PUR), Sodium Dichloroisocyanurate (branded Aquatab), and Chujio ceramic filters as used by the study households. This study was carried out one year after Kenya Water and Health Organisation (KWAHO) ended HWT promotion in their study area and two years after the promotion by Safe Water and Poverty project (SWAP) stopped[2].

6.2.1 Study area

The household water treatment (HWT) assessment was conducted in five of the ten intervention villages in which the KAP and adoption surveys were conducted (Table 6.1); none of the control villages was included in the HWT assessment. The villages were Kinasia, Akado, Angeyoni, Tito and Kokul situated in the Nyanza province of Kenya. The study area has been earlier described in Section 2.2 and the study population in Chapter Three. Surface water was the major type of unimproved water used in the non-rainy season; the general practice was the daily collection of drinking water early in the morning.

6.2.2 Sampling method

A total of 37 households from five villages were used for the HWT assessment (Table 6.1), refer to Chapter Two, Section 2.4.1.

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[2] The fourth method, ceramic filters though promoted, was not used by any household within the KWAHO and SWAP intervention areas. Ceramic filters were thus selected from the intervention site of Women Institute of Secondary Education and Research (WISER).

Table 6.1 The household water treatment technology assessed in specific villages and type and number of sources used by the households during the assessments.

Village	HWT technology	Water source category	Water source type	No. of sources	No. of study HH using sources
Tito	Ceramic filters	Unimproved	Surface water - stream	2	2
			Surface water - pond		1
		Improved	Rainwater		7
Total					10
Angeyoni	Aquatab	Improved	Borehole with handpump	1	1
			Rainwater		2
Akado	Aquatab	Unimproved	Unprotected handdug well	1	3
		Improved	Public standpipe	1	1
			Rain water		2
Total					9
Kokul	Waterguard	Unimproved	Surface water	1	9
		Improved	Rainwater	1	1
Total					10
Kinasia	PUR	Unimproved	Surface water	3	7
		Improved	Rainwater	1	1
					8
Grand total				*11	37

Figure 6.1 Household water treatment technologies. Top: PUR, Waterguard, ceramic filter. Bottom: Aquatab, Waterguard.

6.2.3 Water sampling and questionnaire administration

The general procedure of water sampling has previously been described in Section 2.6.4. The water samples from the collection containers used by the sampled households represented the quality before treatment, and those from the storage container represented the quality after treatment. A total of 247 water samples were collected for analysis in the three assessments; 107 from storage containers, 107 from collection containers and 33 from the 11 sources used by the households (Appendix 6.1). A questionnaire, which was an excerpt from the adoption survey questionnaire, was also administered to the households during the unannounced visits to collect information about the households' water collection, storage and treatment practices. A total of 98 questionnaires were administered.

6.2.4 Experimental procedures

The samples were analysed for total coliforms and *E. coli,* as previously described in Section 2.6.3. .

6.2.5 Data analysis

The following aggregate measurements, adapted from Sobsey *et al.,* (2008), McLaughlin *et al*. (2009) and Albert *et al.* (2010) were used to assess product performance:

(a) Geometric and arithmetic means of *E. coli*/100 ml and total coliforms/100 ml in the water samples before and after treatment with each HWT method. Data was transformed into log because of the log-normal distribution of absolute coliform counts. Concentrations below 1 were recorded as a log value of -1 to retain them after the log transformation. Water in the collection container represented before treatment concentrations, while the storage container samples represented the treated water concentrations because the water treated by the technology was taken from the collection container and not the source.

(b) The base 10 log reductions in *E. coli* and total coliform concentrations before and after treatment. In cases where the concentration was zero after treatment, the value was reported as 'greater than' the maximum reduction detected and a value of one-half the

WHO (2008) maximum log reduction value was used as the surrogate concentration to allow for data analysis, as adapted from McLaughlin *et al*. (2009).

(c) Log reduction value: Log_{10} pre-treatment concentration minus $\log_{10}$ post-treatment concentration (Sobsey *et al*., 2008)

(d) The percentage reductions in the indicator organisms before and after treatment with each HWT technology. Appendix 6.2 shows how log reductions were converted to percentage reduction. This was measured against the baseline log reduction value for each technology which is typically expected when operators lack skill and support (Sobsey *et al.*, 2008; WHO, 2008).

(e) The proportion of acceptable samples that complied with the WHO (2008) drinking water guidelines for *E. coli* and the Sphere Project (2004) guidelines for total coliforms before and after treatment. Microbial quality is reported against the WHO (2008) Drinking Water Quality Guidelines for *E. coli*: < 1 cfu/100 ml and the Sphere Project (2004).for total coliforms: < 10 cfu/100 ml

The results from (a)–(d) were used to assess each HWT method based on the following criteria:

(a) Microbial efficacy.

(b) Robustness: the ability to treat water source with high microbial load (Sobsey *et al.*, 2008)

(c) Performance in relation to sector guidelines (Appendix 6.3: WHO, 2011).

The observed differences in water quality and performance of the technologies were tested for significance with one way Analysis of Variance using Statistica version 9. After which Tukey Honestly Significant Difference post-hoc test was used to identify the variables that were responsible for any significant difference. The significant value was set at 0.05 at the 95% confidence level.

6.3 Results

6.3.1 Context of household water treatment technology assessment

The major source of water used by the households in which the three rounds of household water treatment (HWT) assessments were carried out was unimproved water (69.07%), which was mainly surface water (60.20%). A third of the households (34.02%) used improved water sources (34.02%), of which the main type was rainwater (24.49%). Appendix 6.4 shows that the mean turbidity of all the water sources used for the assessment exceeded the WHO guidelines of 0.1 NTU falling within a range of 210 NTU for surface water which had the highest turbidity and 4.63 for the public standpipe, the lowest. Rainwater had a mean turbidity of 10.28 (range 4.5–200). The majority (91.48%) of users treated water on the day of the assessment, two-thirds treated 20 l/day and the remaining one-third treated 10 l/day. During the three assessments, the unimproved sources had higher arithmetic mean *E. coli* concentrations than the improved sources. For example, the unimproved source samples used to test Aquatab in the three assessments had an arithmetic mean concentration of 426.67±262.30 cfu/100 ml compared to 61.78±98.29 cfu/100 ml for samples from improved sources.

6.3.2 Microbial efficacy of selected household water treatment technologies

The percentage of treated samples that complied with drinking water guidelines for E. coli and total coliforms

Table 6.2 indicates that there was no significant difference between the technologies in the percentage of samples that complied with the WHO drinking water guidelines for *E. coli* before treatment. The trend of the assessments when the samples from the two water source categories (improved and unimproved) were combined and not differentiated, indicates that the percentage of samples that complied with the drinking water guidelines for *E. coli* increased after treatment with all the methods, except for the 1st assessment of PUR in which there was no difference (Figure 6.2).

Table 6.2 Percentage of samples from the household collection and storage containers that met the guidelines for *Escherichia coli* and total coliforms in drinking water during the three HWT assessments.

Stage of assessment	**Technology**				**p-value**
	Ceramic filter	PUR	Aquatab	Waterguard	
Escherichia coli					
Before treatment	16.67	40.00	44.43	10.00	0.09
After treatment	84.43	54.00	81.50	46.70	0.29
Total coliforms					
Before treatment	0.00^{b}	0.00^{b}	15.00^{a}	0.00^{b}	*0.00*
After treatment	22.23	0.00	36.90	0.00	0.24

Significance established using the Tukey Honestly Significant Difference test at 0.05 error level and 95% confidence level; p-values < 0.05 were considered significant. Superscript letters show the relationship between technologies, similar letters indicate that there is no significant difference, while different letters indicate a significant difference.

The percentage of samples that complied with the WHO drinking water guidelines for *E. coli* increased after treatment with ceramic filters from 16.7%–84.4%, with Aquatab from 44%–81.5%, with PUR from 29%–54%, and after treatment with Waterguard from 10%–46.7%. Table 6.2 shows that although all the HWT methods were able to increase the percentage of samples that complied with the drinking water guidelines for *E. coli* after treatment, there was no significant difference between the technologies (p = 0.29) in the increase.

Ceramic filters had the highest percentage of samples that met the WHO guidelines, though they did not attain 100% compliance in any of the three assessments. Only Aquatab and PUR achieved an efficacy in which 100% of the samples complied with the drinking water guidelines after treatment, but only once during the three assessments.

The majority of the samples did not comply with the Sphere Project (2004) drinking water guidelines for total coliforms even after treatment with the four HWT technologies, with no significant difference in the performance of the technologies (Figure 6.2).

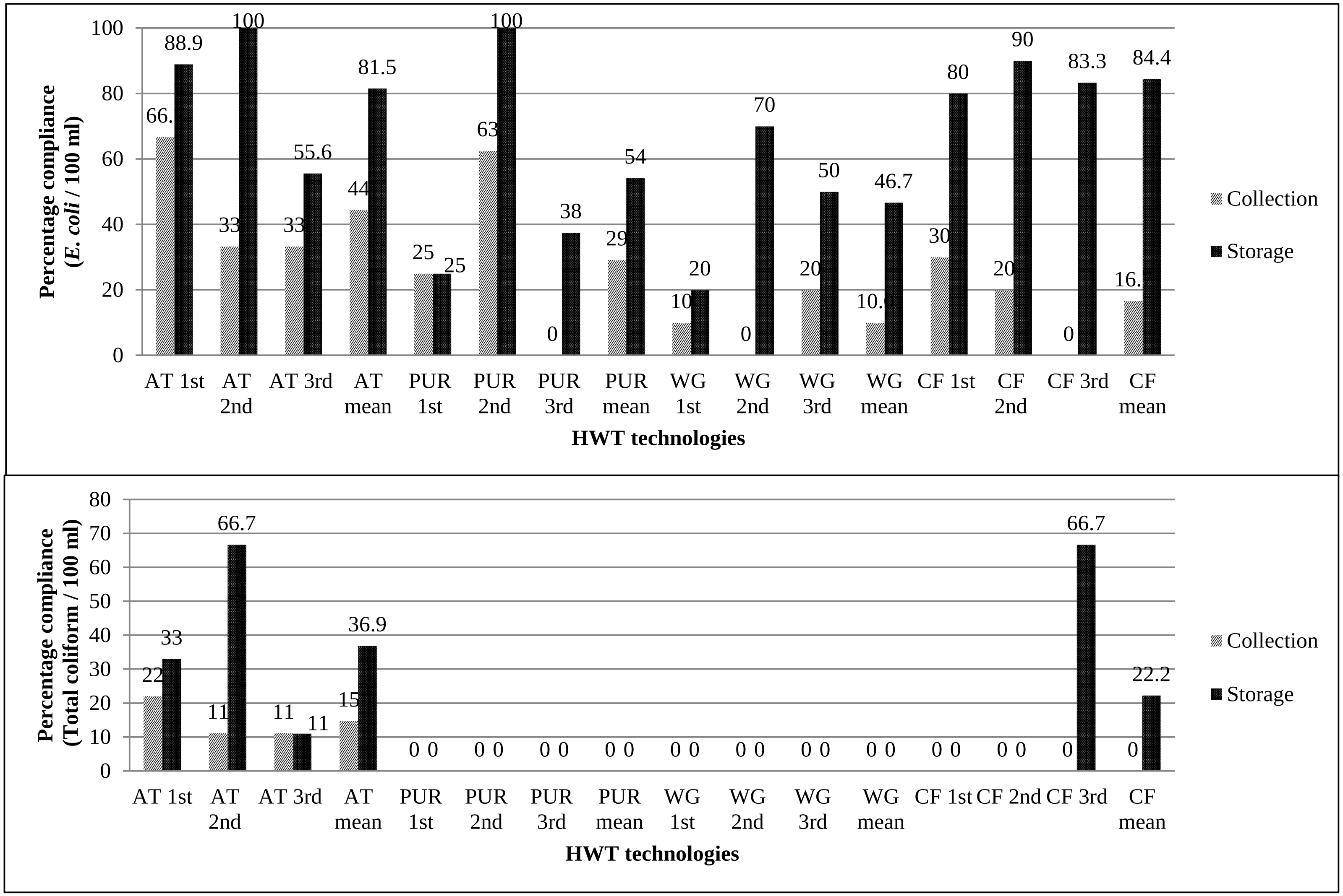


Figure 6.2 Percentage of water samples that conformed to drinking water guidelines for *E. coli* and total coliforms before and after treatment. AT: Aquatab n = 9; WG: Waterguard n = 10; CF: ceramic filters n = 10; PUR n = 8 HWT: household water treatment.

Mean log reduction value and percentage reduction for each of the HWT technologies before and after treatment

There was no significant difference in the arithmetic mean concentrations of *E. coli* of the combined (improved and unimproved water sources) samples used to assess the performance of Waterguard, PUR and Aquatab (Table 6.3). Table 6.3 shows that the *E. coli* concentrations of the samples used to test the ceramic filter were significantly higher than those used to test the other three HWT methods ($p < 0.00$). For example, the arithmetic mean concentration of combined water samples used to test the performance of the ceramic filters was 2 976.90±3 160.04 cfu/100 ml compared to 157.50±392.77 ^{b} cfu/100 ml for samples used to test PUR.

Table 6.3 Arithmetic mean concentration of *Escherichia coli* in water samples from source and collection containers used for the household water treatment technology assessments

Water source category	**Technology**				**p-value**
	Ceramic filter	PUR	Aquatab	Waterguard	
Collection unimproved	4 136.3 ±3 592.76 ^{b}	629.09 ±1 035.27 ^{a}	45.56 ±63.66 ^{a}	887.86 ±1 100.67 ^{a}	0.00
Collection improved	94±187.75 ^{b}	780±1032.38 ^{a}	107.78±241.97 ^{b}	1 000±0 ^{a}	0.00
Collection combined*	2 581.53±3 432.13 ^{a}	641.67±1013.28^{b}	87.04±201.05 ^{b}	862.0^{b}	0.00
Source unimproved	4 837.5±2653.78 ^{a}	171.36±408.1 ^{b}	426.67±262.30 ^{b}	1 303.45±1528.18 ^{b}	0.00
Source improved	0	5±7.07	61.78±98.29	0	0.23
Source combined*	2 976.9±3 160.04 ^{a}	157.5±392.77 ^{b}	183.41±241.27 ^{b}	1 260.0±1 520.35 ^{b}	0.00

Tukey Honestly Significant Difference test was used. Common superscript letters indicate no significant difference between technologies while different letters denotes a difference; *Combined samples refer to assessments in which the sources were not stratified by category but jointly assessed.

Table 6.4 shows the arithmetic mean concentrations of *E. coli* in the household water samples before and after treatment with the HWT technologies. Details of the range of *E. coli* and total coliform concentrations during the three assessments are shown in Appendices 6.5–6.10.

Table 6.4 shows that in spite of the fact that the ceramic filters were used to treat water that was significantly poorer in quality than the water used to test the other three technologies, there was no significant difference between the four technologies in arithmetic mean *E. coli* concentrations of the treated water when the water source categories were combined (p = 0.53)

Table 6.4 Arithmetic mean concentration of *Escherichia coli* in household collection and storage containers before and after treatment.

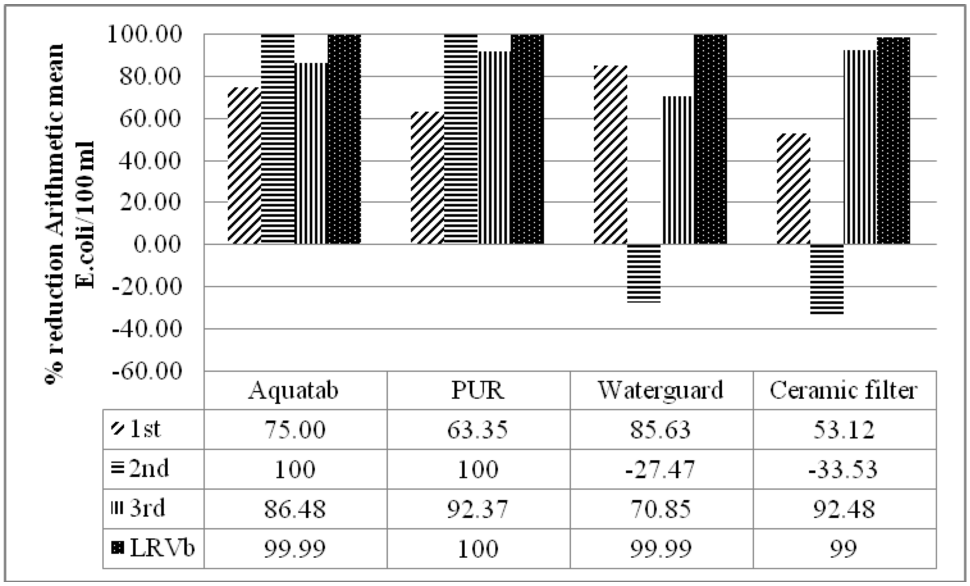
Water source category	**Technology**				**p-value**
	Ceramic filter	PUR	Aquatab	Waterguard	
Collection unimproved	4 136.3 ± 3592.76^{b}	629.09 ± 1035.27^{a}	45.56 ± 63.66 ^{a}	887.86 ±1 100.67 ^{a}	0.00
Storage unimproved	456.25±1798.51	122.27±263.40	177.77±46.03	107.97±142.89	0.50
Collection improved	94±187.75 ^{b}	780±1032.38 ^{a}	107.78±241.97 ^{b}	1 000±0 ^{a}	0.00
Storage improved	46±141.99 ^{b}	55± 63.64 ^{ab}	7.78±21.02 ^{a}	300±0 ^{b}	0.02
Collection combined	2 581.53±3432.13 ^{a}	641.67±1013.28^{b}	87.04±201.05 ^{b}	862.0^{b}	0.00
Storage combined	298.46±1410.48	116.67±252.75	11.11±31.05	114.37±144.71	0.53

Samples in collection containers represent *E. coli* concentrations before treatment; samples in storage containers represent the concentrations after treatment.

Figures 6.3 and 6.4 show the mean percentage reduction in *E. coli* and total coliform concentrations respectively, in the combined samples after household treatment with the HWT technologies during the 1st, 2nd and 3rd assessments.

The highest mean percentage reduction and mean log reduction in *E. coli* concentrations achieved by the HWT methods was 100% ($\log_{10} > 1.85$) by Aquatab, 100% ($\log_{10} > 1.80$) by PUR, 92.48% ($\log_{10}$ 1.12) by ceramic filters and 85.63% ($\log_{10}$ 0.84) by Waterguard

(Figure 6.3). Table 6.5 shows that there was no significant difference in the mean log reductions in *E. coli* concentrations achieved by the four technologies during the three assessments (p = 0.51)



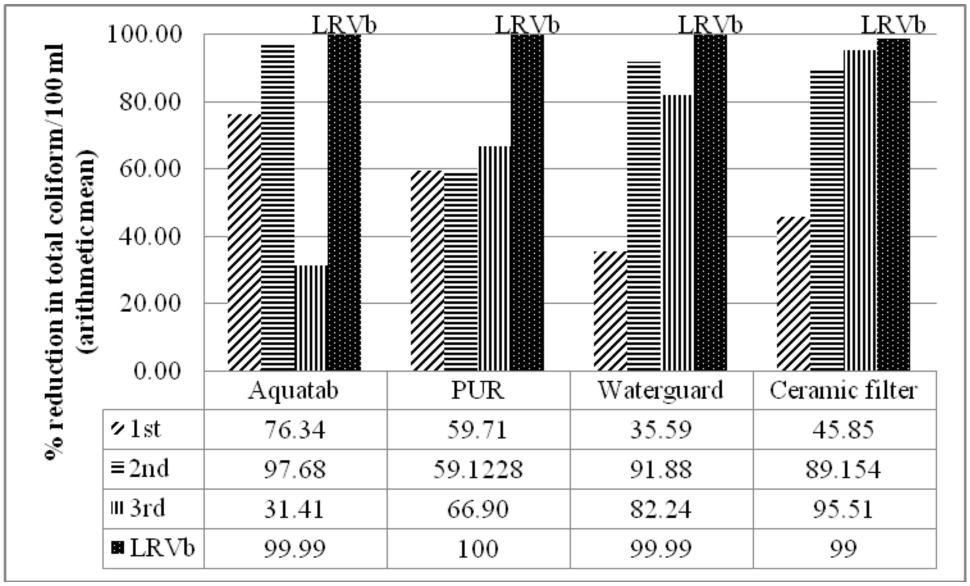
	Aquatab	PUR	Waterguard	Ceramic filter
⫽ 1st	75.00	63.35	85.63	53.12
≡ 2nd	100	100	-27.47	-33.53
⦀ 3rd	86.48	92.37	70.85	92.48
▩ LRVb	99.99	100	99.99	99

Figure 6.3 Performance of HWT technologies in combined (improved and unimproved) water sources
(Arithmetic mean *E. coli*/100 ml). LRVb: % reduction: percentage reduction in arithmetic mean concentration between collection and storage container samples

Table 6.5 Mean log reduction of *Escherichia coli* concentration of household drinking water after treatment with HWT technologies.

Water source category	**Technology**				**p-value**
	Ceramic filters	PUR	Aquatab	Waterguard	
Unimproved	1.57	2.0	1.06	0.44	0.65
Improved	0.16	0.94	2.3	1.43	0.64
Combined sources	0.04	0.78	1.49	0.54	0.51

The highest mean percentage reduction and mean log reduction achieved by the HWT technologies in total coliform concentrations of the combined samples was 97.68% ($\log_{10}$ 1.64) by Aquatab, 95.51% ($\log_{10}$ 35) by ceramic filters, 91.88% ($\log_{10}$ 1.09) by Waterguard and 66.90% ($\log_{10}$ 0.48) by PUR, and (Figure 6.4).



	Aquatab	PUR	Waterguard	Ceramic filter
▨ 1st	76.34	59.71	35.59	45.85
≡ 2nd	97.68	59.1228	91.88	89.154
⦀ 3rd	31.41	66.90	82.24	95.51
▩ LRVb	99.99	100	99.99	99

Figure 6.4 Performance of HWT technologies in combined (improved and unimproved) water sources (Arithmetic mean total coliforms/100 ml). LRVb:

Baseline log reduction value typically expected when operators lack skill and support. % reduction: percentage reduction in arithmetic mean concentration between collection and storage container samples

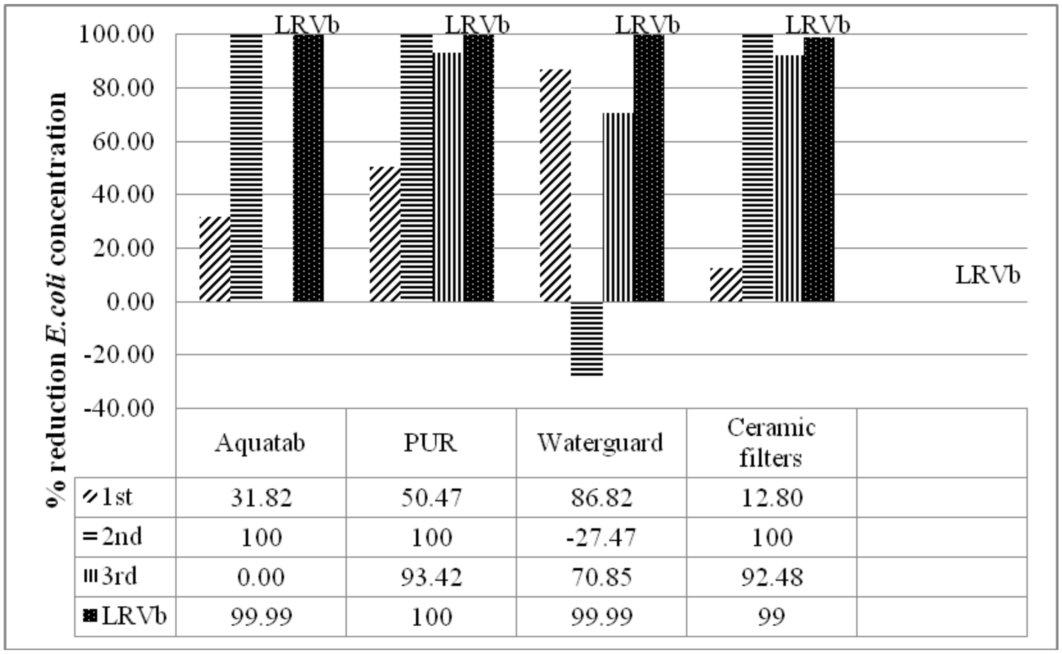
Aquatab met the WHO HWT technology minimum performance standard of 99.9% ($\log_{10}3$) in *E. coli* reduction but did not do so in any of the three assessments for total coliforms. PUR met the performance standard of 100% ($\log_{10} 7$) in one of the three assessments for *E. coli* and one of the three assessments for total coliforms. Waterguard did not meet the minimum performance standard of 99.9% ($\log_{10} 3$) in any of the assessments for *E. coli* or total coliforms, nor did the ceramic filters for either *E. coli* or total coliform reduction (Figure 6.3 and Figure 6.4).

6.3.3 Assessment of robustness of technology performance

Figures 6.5 and 6.6 show the mean percentage reduction values in *E. coli* and total coliform concentrations respectively in samples from unimproved water sources after treatment with the HWT technologies.

The highest mean percentage reduction and mean log reduction in *E. coli* concentrations of the samples from unimproved water sources, achieved by the HWT technologies was

100% ($\log_{10} > 3.86$) by ceramic filters, 100% ($\log_{10} > 1.78$) by Aquatab, 100% ($\log_{10} > 1.80$) by PUR and 86.82% ($\log_{10}$ 0.88) by Waterguard (Figure 6.5).

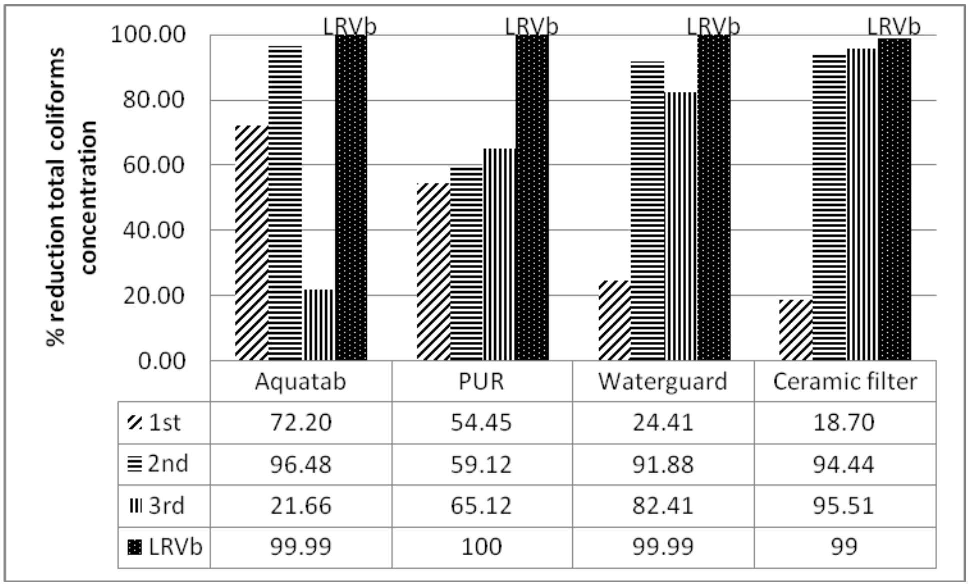


	Aquatab	PUR	Waterguard	Ceramic filters	
⁄ 1st	31.82	50.47	86.82	12.80	
= 2nd	100	100	-27.47	100	
III 3rd	0.00	93.42	70.85	92.48	
■ LRVb	99.99	100	99.99	99	

Figure 6.5 Performance of HWT technologies in unimproved water sources (*E. coli*/100 ml). LRVb: Baseline log reduction value, typically expected when operators lack skill and support. % reduction: percentage reduction in arithmetic mean concentration between collection and storage container samples.

There was no significant difference between the four technologies in arithmetic mean *E. coli* concentrations of the water samples from unimproved sources after treatment ($p = 0.05$), even though as earlier shown in Table 6.4, the water sources used to test ceramic filters were significantly higher in *E. coli* concentrations, before treatment than those used to test the other three technologies ($p < 0.00$).

The highest mean percentage reduction and mean log reduction in total coliform concentrations in samples from unimproved water sources achieved by the HWT technologies was 96.48% ($\log_{10}$ 1.45) by Aquatab, 95.51% ($\log_{10}$ 1.35) by ceramic filters, 91.88% ($\log_{10}$ 1.09) by Waterguard and 65.12% ($\log_{10}$ 0.46) by PUR (Figure 6.6).



	Aquatab	PUR	Waterguard	Ceramic filter
▨ 1st	72.20	54.45	24.41	18.70
≡ 2nd	96.48	59.12	91.88	94.44
⦀ 3rd	21.66	65.12	82.41	95.51
■ LRVb	99.99	100	99.99	99

Figure 6.6 Performance of HWT technologies in unimproved water sources (total coliforms/100 ml).

When used to treat unimproved water sources, Aquatab met the WHO HWT technology minimum performance standard in *E. coli* reduction in one out of the three assessments but did not do so in any of the three assessments for total coliforms. PUR met the performance standard in one of the three assessments for *E. coli*, Waterguard did not meet the minimum performance standard in any of the assessments for *E. coli* or total coliforms. The ceramic filters reduced the *E. coli* concentrations to above the minimum performance standards in one out of the three assessments.

None of the technologies showed a significant difference between their performance in treating improved and treating unimproved water sources, although only one of the Waterguard-user households used an improved water source (Table 6.6).

Table 6.6 Performance of technologies after treatment of unimproved and unimproved water sources (Arithmetic mean *Escherichia coli* cfu/100 ml).

Technology	Unimproved	Improved	p-value
Ceramic filter	456.25±1 798.51	46.00±141.99	0.48
PUR	122.27±263.40	55.00±63.64	0.73
Aquatab	177.78±46.03	7.78±21.02	0.44
Waterguard	107.97±142.89	300.00±0	0.20

6.3.4 Performance of each household water treatment technology against sector standards

Table 6.7 shows the mean log reduction achieved by each HWT technology when used to treat household water from improved, unimproved and combined sources.

Aquatab did not achieve either the highly protective log reduction (≥ 4) or protective (≥ 2) levels as classified by WHO (2011) in its standards for assessing the performance of HWT technologies (Table 6.7).

Similarly, the observed log reduction values are below the LRVb for PUR of log 7. The protective effect of > 2 log reduction is only observed once out of the six times PUR's performance was assessed for *E. coli* and total coliforms reductions. Even though its effect on viruses and protozoa was not determined, the log reductions observed for bacterial reductions indicate that PUR does not meet the highly protective or protective levels of performance under these real-world conditions (Table 6.7).

Waterguard did not attain its expected LRVb of log 3 for either total coliforms or *E. coli* during any of the six observations of performance, rather it showed an increase in mean *E. coli* concentrations in one out of the three assessments when used to treat water collected from unimproved sources. Waterguard's performance in reducing microbes in stored water collected from unimproved and improved water sources shows that it cannot be classified as a technology that provides a highly protective or protective level to its users in the circumstances in which its performance was examined in this study (Table 6.7).

Ceramic filters achieved an *E. coli* concentration reduction which exceeded the LRVb of log 2 when used to treat unimproved water sources, once out of the three times ceramic filter effectiveness was assessed. This was however an exception as the range of reductions for both *E. coli* and total coliforms was in most cases below 0.5 log reductions, with very few observations attaining a 1 log reduction. Based on these observations, ceramic filters as used by these communities do not offer a highly protective or protective level of performance (Table 6.7).

Table 6.7 Summary of $\log_{10}$ reduction values achieved by household water treatment technologies in the three assessments and compliance with baseline log reduction values.

		HWT technologies and baseline log reduction value																							
Source category	**LRV and Compliance**	**Aquatab (LRVb = 3)**						**PUR (LRVb = 7)**						**Waterguard (LRVb = 3)**						**Ceramic Filter (LRVb = 2)**					
		E. coli			Total coliforms			*E. coli*			Total coliforms			*E. coli*			Total coliforms			*E. coli*			Total coliforms		
		Assessments																							
		1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Unimproved	LRV	0.17	>1.78	0	0.56	1.45	0.11	0.31	>1.80	1.18	0.37	0.39	0.46	0.88	**-0.11**	0.54	0.12	1.09	0.75	0.60	>3.86	1.12	0.09	1.25	1.35
	Compliance with LRVb	1 of 3			0 of 3			1 of 3			0 of 3			0 of 3			0 of 3			1 of 3			0 of 3		
Improved	LRV	>1.80	>1.88	0.9	0.70	2.60	0.26	2.18	N/A	***>-0.3***	0.79	N/A	2.77	0.52	N/A	N/A	1.43	N/A	N/A	1.97	**-1.65**	N/A	0.41	0.12	
	Compliance with LRVb	2 of 3			0 of 3			0 of 2			0 of 2			0 of1			0 of 1			0 of 2			0 of 3		
Combined	LRV	0.6	>1.85	0.87	0.63	1.64	0.16	0.44	>1.8	1.12	0.40	0.39	0.48	0.84	**-0.11**	0.54	0.19	1.09	0.75	0.33	**-0.26**	1.12	0.27	0.97	1.35
	Compliance with LRVb	1 of 3			0 of 3			1 of 3			0 of 3			0 of 3			0 of 3			0 of 3			0 of 3		

Log reduction value: Log_{10} pre-treatment concentration minus $\log_{10}$ post-treatment concentration ; LRVb: Baseline reduction value typically expected when operators lack skill and support. N/A: not applicable because household did not use that category of source during that assessment visit.

6.3.5 Summary of performance and ranking of technologies

Table 6.8 indicates that PUR was ranked 1st and Waterguard 4th in robustness, which was taken as the technology's performance when used to treat water from unimproved sources. Aquatab was ranked 1st and ceramic filters 4th in microbial efficacy, using their performance in the combined (unimproved and improved) sources. In terms of performance against sector standards, Aquatab was ranked 1st and Waterguard 4th.

Table 6.8 Summary performance and ranking of selected household water treatment technologies using three assessment criteria (*E. coli* as indicator organism).

Criterion	Technology performance and ranking				p-value
	Ceramic filters	PUR	Aquatab	Waterguard	
Mean log reduction in unimproved sources	1.57 (2nd)	2 (1st)	1.06 (3rd)	0.44 (4th)	0.65
Mean log reduction in improved sources	0.16 (4th)	0.94 (3rd)	2.3 (1st)	1.43 (2nd)	0.64
Mean log reduction in combined sources	0.04 (4th)	0.78 (2nd)	1.49 (1st)	0.54 (3rd)	0.51
Number of times mean log reduction attained LRVb	1 in 8 (3rd)	2 in 8 (2nd)	4 in 9 (1st)	0 in 8 (4th)	N/A

LRVb: Baseline log reduction value, typically expected when operators lack skill and support . Nine assessments carried out in total per technology for *E. coli*, however PUR, Waterguard and ceramic filters did not have any household using improved sources in at least one out of the assessments for improved sources.

6.4 Discussion

6.4.1 Context of the household water treatment assessment

In these study communities and others like them, it is critical that an HWT technology should effectively improve the quality of their grossly polluted sources to acceptable drinking water guidelines. For example, more than two-thirds of the respondents in this study, used unimproved water sources none of which met the WHO (2008) guideline of < 1 cfu/100 ml for *E. coli* concentrations in drinking water before treatment. The need for HWT technologies to effectively treat water of high organic and microbial load is further underscored by the findings that rainwater which was the main improved water source used in these communities exceeded the drinking water guidelines for total coliform and *E. coli* levels, and had the highest geometric mean *E. coli* amongst the improved sources (8.91±22.35).

The observation in this study that the unimproved sources consistently had higher geometric mean *E. coli* counts than the improved sources during the 1st, 2nd and 3rd HWT assessments (Table 6.3) supports the view of Momba *et al.* (2008), that a protected improved water source is the first level of effective treatment. This study observed an arithmetic mean *E. coli* load of 4 837.5±2 653.78 cfu/100 ml and 0 cfu/100 ml respectively, in the unimproved and improved sources used to test ceramic filter performance (Table 6.3). This finding is consistent with the findings of a geometric mean load of 602 cfu/100 ml for river water in a study in Kenya by Albert *et al*. (2010), which they noted was significantly higher than the mean concentrations of rain and tap water (231 and 248 cfu/100 ml respectively).

6.4.2 Technical performance of household water treatment technologies

Consistency in performance of HWT Technologies

None of the four HWT methods was consistent in their ability to improve the quality of the treated water to the accepted drinking water guidelines for either *E. coli* or total coliforms when consistency was taken as the ability to meet the standards in a minimum of two of the three assessments (Figure 6.2). The observation of inconsistent performance agrees with the findings of Bielefeldt *et al.* (2009) in Northern Ecuador, that the microbial efficacy of ceramic filters reduced with usage. The Center for Affordable Water and Sanitation Technology however reported a >98-100% bacterial removal under laboratory conditions (CAWST, 2009). It is also consistent with the findings of Crump *et al*. (2004) in a study in Western Kenya, who reported that neither the combined flocculant-disinfectant (PUR) nor sodium hypochlorite (Waterguard) were able to treat water such that 100% of the samples conformed to the WHO drinking water guideline for *E. coli* of < 1 cfu/100 ml. This study's findings are however contrary to the claims of the manufacturers of PUR, Procter and Gamble, of an efficacy of 99.99999% removal of bacteria or of the Center for Disease Control of 100% bacterial removal during field trials. (CDC, 2012).Though the performance of Waterguard in this study (46.7%) was similar to the 51% reported by Albert *et al*. (2010), Waterguard was found in this study to be the least effective comparatively, but was found to be the most effective by Albert *et al*. (2010). This study's finding agrees with the review by Sobsey *et al.* (2008) that Waterguard was the least effective among other assessed HWT interventions. The difference in findings may be because the majority of samples used in this study were from unimproved sources while those used by Albert *et al*. (2010) were mostly from improved sources.

Performance of HWT technologies in unimproved water sources — robustness

Aquatab performed three times better when used to treat water from improved sources than from unimproved (Table 6.5) though the difference was not statistically significant. This reduction in efficacy agrees with the observation by Clasen and Edmonson (2005) that the mean log reduction value decreased from 4 when Aquatab was used to treat water of low turbidity to between 1.8 and 2.8 when highly turbid water was treated. The mean log reduction observed in this study was less than the expected 6 log reduction in low turbid waters as reported by Medentech, manufacturers of Aquatab (Medentech, 2012).

In contrast, when PUR was used to treat water from unimproved sources, the mean log reduction in *E. coli* was twice the reduction observed when it was used to treat water from improved sources (Table 6.5). This is consistent with the product’s dual treatment objective of turbidity reduction and disinfection and with the report by Crump *et al.* (2004) that the flocculant-disinfectant (PUR) was the only HWT product that reduced *E. coli* concentrations to < 1 cfu/100 ml out of the methods (Waterguard, alum and PUR) tested in a high turbidity setting. Although there was no significant difference between the performance of the selected technologies when used to treat unimproved water sources in this study (Table 6.5), PUR attained the highest mean log reduction of 2.0, while Waterguard had the lowest mean reduction of 0.44.

This is also consistent with the findings of McLaughlin *et al.* (2009) in a study in Northern Ecuador, who found no significant difference between chlorinated and non-chlorinated water samples and attributed this to the high turbidity of the water sources used by the households.

With regard to ceramic filters, the observed changes in mean *E. coli* concentrations after household treatment of water sources with ceramic filters, was not consistent enough to make inferences about the effect of turbidity on the effectiveness of ceramic filters. However when ceramic filters were used to treat unimproved water sources, the mean log reduction in *E. coli* ranged from 0.6–> 3.86. This is consistent with Bielefeldt *et al.* (2009) who initially obtained a 3–4 log reduction in *E. coli* concentrations which decreased to < 1 with subsequent batches of filtration, under laboratory conditions in Northern Ecuador.

6.4.3 Interpretation of findings on effectiveness of HWT technologies in real-world context

The assessed HWT technologies did not perform effectively, robustly or consistently under the real-world conditions of this study. Given that the mean log reduction of the four HWT methods assessed ranged from 0.16–2.3 when used to treat improved water sources and 0.44–2.0 when used to treat unimproved water sources (Table 6.8), none of the assessed technologies can be classified as providing a highly protective or even protective effect.

Though the results obtained in this study are within the range observed in other studies, interpretations of the findings differ. For example, this study noted log reduction values (Waterguard 1.43, PUR 0.94, ceramic filters 0.16: Table 6.5), which are consistent with those reported by Albert *et al*. (2010) (Waterguard 1.21, PUR 0.98 and filters 0.91). They however noted that the technologies exhibited a “solid performance” even though the mean performance across all the three assessed technologies was a log reduction of 1.03 performance which cannot be said to be solid.

This study’s conclusion that the HWT technologies assessed did not perform effectively is supported by the observation by Brown and Sobsey (2012) that an HWT method that shows a mean log reduction of between 1 and 2 is basic and poorly performing.

Differences in observations between this study and those referred to, as well as other HWT studies must be considered in the light of the fact that this study was carried out a year after the KWAHO and two years after the SWAP support and visits to the community had ceased, thus reflecting typical-use scenarios, while the other studies were either carried out during or shortly after the intervention or were artificially created for study purposes. For example, Albert *et al.* (2010) noted that their study households were assigned the products that were evaluated and the longest period of use before the evaluation was 10 weeks. Similarly, Bielefeldt *et al.* (2009) and Brown and Sobsey (2010) who reported positively on the effectiveness of ceramic filters conducted laboratory based studies.

6.5 Conclusion

This study found that within a real-world setting, the four assessed HWT technologies were able to improve the microbial quality of the improved and unimproved water sources used by the study communities. However, none of the technologies performed well enough to be classified as highly protective or protective considering the low percentage of samples that met the drinking water guidelines, as well as the log reduction values which fell below the minimum reductions expected as stipulated by the WHO (2008) and WHO (2011). Consequently, the use of these technologies exposes these users to the health risks of unknowingly consuming poorly treated water. This study’s findings provide evidence to support the view by Sobsey *et al*. (2009) that the promotion of HWT technologies as is currently being done, without implementing measures to improve compliance and correct use by households is akin to promoting risky sexual or water-use behaviour.

7 A QUANTITATIVE MICROBIAL RISK ASSESSMENT OF THE EFFECT OF SELECTED HOUSEHOLD WATER TREATMENT TECHNOLOGIES ON THE POTENTIAL RISK OF WATER-BORNE INFECTIONS IN USERS

7.1 Introduction

The preceding chapter showed that none of the assessed technologies improved the microbiological quality of the treated water to the recommended guidelines consistently for either *E. coli* or total coliforms. Such inconsistent performance supports the view of Schmidt and Cairncross (2008) that HWT should not be promoted because current evidence pointing to their health benefits is biased. However, because the technologies improved household water quality during some of this study’s assessments, and have been shown to be effective in other studies under laboratory and field testing conditions, it is necessary to assess their ability to reduce the risk of water-borne infections. The findings will indicate whether there is a potential health benefit to the use of HWT technologies at the levels of effectiveness observed in the typical-use conditions of this study. This is in line with the rationale of WHO (2001) that the risk of infection from a pathogen may be used to ascertain whether it is a hazard to public health.

In order to harness the health benefits of safe water provision for consumers, the WHO recommends the use of a drinking water quality framework undergirded by the principles of catchment-wide risk analysis and risk management (WHO, 2008).

A risk assessment method can be used to demonstrate the benefits of HWT and other interventions by estimating the changes in exposure to and the probability of infection with the hazard after the intervention (Abongo *et al*., 2008). Risk assessments are important because they can be used to demonstrate the link between the reduction in disease prevalence and water quality improvements even when it is difficult to do this with routine epidemiological methods (Haverlaar and Melse, 2003; WHO, 2008). Furthermore, though various studies have used epidemiological methods to show a reduction in diarrhoeal disease in households that use HWT methods, some authors have attributed the reported disease reduction to bias (Schmidt and Cairncross, 2008; McLaughlin *et al.*, 2009).

Critics have cited the respondents' need to recall diarrhoeal incidences and attributed the higher effect size to the support given to the treatment households but withheld from the controls (Blum and Feachem, 1983; Schmidt and Cairncross, 2008; McLaughlin *et al.*, 2009). For example, du Preez *et al.* (2010) observed no significant difference in diarrhoeal illnesses between study households who used solar disinfection but were not highly motivated and those who did not treat their water. Risk assessments are important in drinking water treatment management because they demonstrate that the critical health objective of water supply provision is being met (Medema and Ashbolt, 2006).

Risk assessments are however subject to various limitations because of the assumptions made in applying dose-response relationships to populations with varying health status and immunity; and relating them to pathogens with varying infectivity and survival rates (Teunis *et al*., 2004; van Lierveloo *et al.*, 2007; Brown and Clasen, 2012). Nonetheless, though there is room for improvement in QMRA's use of assumptions and uncertainty in the data used to arrive at estimates of risks, a QMRA is relevant to both the developing and industrialised worlds (van Lieverloo *et al*., 2007; Brown and Clasen, 2012).

Some drinking water quality studies have used QMRA to quantify the health risks of pathogens (Haas *et al.*, 1993) and chemical contaminants (Erdal and Buchanan, 2005) in drinking water, the risks of disease during outbreaks (Teunis *et al*., 2004; Lieverloo *et al.*, 2007) and the health risks attributable to different kinds of water supply (Howard *et al*., 2006). Others have compared the health risks of pathogens in drinking water with the risk of disinfection-by-products of chlorination (Ashbolt, 2004b), ingestion of water during domestic and recreational use (Steyn *et al.*, 2004) and the effect of adherence on the health gains from HWT technologies (Brown and Clasen, 2012).

This study used a basic quantitative microbial risk assessment approach to assess the effect of selected HWT methods used in Kenya on the shift in risk of infection by comparing their ability to reduce exposure to and probability of infection by *water-borne pathogens* (using *E. coli* as an indicator) in users of the HWT technologies after ingestion of untreated and treated water. Reduced exposure and a lowered probability of infection are used as proxy indicators for the health benefits of the household water treatment technologies. Though the output of a QMRA is the distribution of health risk from a pathogen through the consumption of food or water contaminated with the pathogen (Abongo *et al*., 2008), this study used a QMRA to provide knowledge about the potential health benefit of HWT to users using the difference in exposure and risk of infection after household water treatment, rather than the actual distribution of risk from the exposure. Though the study did not calculate the shift in disease burden due to the effect of the HWT, the approach used in assessing health benefits of HWT at the post-implementation levels of effectiveness, is justified on the premise that when water is a major source of exposure to pathogens, a reduction in exposure to the pathogens, will lead to an improvement in health (Brown and Clasen, 2012).

7.2 Methods

This QMRA was carried out in the same five intervention villages and 37 households where the effectiveness of the four HWT technologies was assessed (Table 7.1). This was done using the following steps adapted from Hunter *et al.* (2003): hazard identification, exposure assessment and risk characterisation.

7.2.1 Problem formulation and hazard identification

The socio-economic setting was assessed by conducting a knowledge, attitudes and practices (KAP) survey in the fifteen villages which formed the sampling frame from which the five study villages for the quantitative microbial risk assessment study were selected. In addition to the KAP survey, the findings from the questionnaire administered during the HWT effectiveness assessment was incorporated into the hazard identification.

Table 7.1 Water samples used for assessment of change in risk of infection by household water treatment technologies.

Technology	Village	Type of sources	Category of source	At source	At collection	At storage
Aquatab	Angenyoni and Akado	Unprotected handdug well	Unimproved	9	9	9
		Borehole with handpump & rain water	Improved	18	18	18
			Total	27	27	27
PUR	Kinasia	Surface water	Unimproved	22	22	21
		Rainwater	Improved	2	2	3
			Total	24	24	24
Waterguard	Kokul	Surface water	Unimproved	29	29	29
		Rainwater	Improved	1	1	1
			Total	30	30	30
Ceramic filters	Tito	Surface water	Unimproved	16	16	16
		Rainwater	Improved	10	10	10
			Total	26	26	26
Grand Total				107	107	107

The environmental health setting was potentially a high-risk one because of environmental health factors such as overcrowding, inadequate access to safe water and poor sanitation. Only one in two households used improved water sources and only one in twelve used improved sanitation. The household size suggested overcrowding which in addition to the inadequate water supply and sanitation, exposed these households to hazards of water-borne and other enteric diseases (Ashbolt, 2004a). Furthermore, although a majority of the households (91.4%) treated water on the day of the assessment, less than half the users of the four HWT methods were familiar with the three most critical steps for effective use of the HWT technologies, thus increasing their exposure to water-borne pathogens, particularly because the arithmetic mean concentration of

E. coli of the water sources used by the study communities suggested faecal contamination (Appendices 6.6 to 6.11).

The exposed population was identified from the results of the adoption survey in which the majority reported that they did not drink any untreated water. All the inhabitants of the five selected villages were taken to be the exposed population because both improved and unimproved water source categories were contaminated. Adults above 18 years of age were selected as the study population at-risk, and the average quantity of drinking water consumed by the respondents per day as determined from Chapter Four was used to calculate exposure.

7.2.2 Choice of pathogen and indicator organism

QMRAs are not carried out for every pathogen because it would be time consuming and impractical to carry out a QMRA for every pathogen of interest. Reference pathogens are therefore used in QMRAs because of the unavailability of dose-response models for every pathogen of interest. Howard *et al*. (2006) noted that the limited data on pathogens in developing countries necessitates the use of indicator organisms in conducting a QMRA. In this study, *E. coli* was chosen as the indicator of preference because of its use as a universal indicator of the potential presence of other water-borne pathogens, whose route of drinking water contamination is faeces (Ashbolt *et al*., 2001; WHO, 2008). However this suggests that every *E. coli* isolated in this study is pathogenic, though this is not the case, as according to WHO (2008) *Escherichia coli* is a normal intestinal flora of humans. To adjust for this assumption and to avoid an overestimation of the exposure and probability of infection, the ratio of *E. coli to E. coli* O157:H7 as calibrated by Enger *et al*. (2012) and the dose-response model for *E coli* O157:H7 (Abongo *et al.,* 2008) was used to estimate the shift in pathogen exposure and probability of infection. *E.coli* O157:H7 was selected because it is an enterohaemorrhagic *E. coli* (EHEC*)* serotype, which causes acute diarrhoea, has high public health significance as a water-borne pathogen in drinking water especially in developing countries (WHO, 2008). Furthermore, there is no evidence currently to suggest that *E coli* O157:H7 differs from other *E.coli* in its response to water treatment procedures (WHO, 2008), and tests for thermotolerant coliforms or *E.coli* provide an appropriate index for the presence of EHEC strains (WHO, 2008).

Consequently, taking into cognisance the assumptions made and the study objective, this study uses the term risk of infection from water-borne pathogens (using *E. coli* as indicator). This approach can be justified because the study does not aim to predict the levels of risk from a specific water-borne pathogen ingested through drinking water, but to investigate the effect of HWT if any, on the levels of exposure and probability of infection of HWT users.

7.2.3 The exposure assessment

The study determined the probability of exposure to and risk of infection from water-borne pathogens using *E. coli* counts in drinking water samples before and after treatment with the selected technologies. The quantitative determination of the *E coli* concentration before and after treatment with the selected household water treatment technologies was calculated in the following steps:

a. Quantification of the *E. coli* concentration of 107 water samples from the collection containers and 107 water samples from the drinking water storage containers of the 37 households using the HWT technologies. Table 7.2 shows the geometric mean concentration of *E. coli* in samples taken from the collection and drinking water storage containers of the study households during the first of three assessments, representing water quality before and after treatment. For example, the geometric mean *E. coli* load of the unimproved drinking water samples used to test Waterguard and taken from the household collection and storage containers was 362.69±14.77 and 56.38±11.35 respectively. Further details are shown in Appendix 6.5.

b. Quantification of the volume of untreated and treated water consumed by the adult respondent and youngest child using the adoption and survey KAP results. A single estimate of average quantity of water consumed per person per day (1 025 ml) was calculated from the daily consumption per respondent in each of the five villages (Table 7.3).

c. Determination of dose before and after treatment by multiplying the average quantity of water (1 025 ml) consumed with the *E.coli* O157:H7: *E. coli*/100 ml concentration (Enger *et al*., 2012) in drinking water at collection and storage (Table 7.3).

Table 7.2 Geometric mean, percentage and log reductions in *Escherichia coli* concentrations in drinking water samples before and after treatment with specific household water treatment technologies at first assessment.

Technology	Source category	No. of households & samples at collection	No. of households & samples at storage	GM mean EC/100 ml±SD at collection	GM mean EC/100 ml±SD at storage	% reduction	log reduction
Aquatab	Unimproved	3	3	19.31±14.47	11.187±11.87	38.53	-0.21
	Improved	6	6	2.69±11.30	0	62.83	-0.43
	Total	9	6	5.19±12.63	2.24±5.63	56.84	-0.37
PUR	Unimproved	7	7	95.26±25.11	100.37±9.31	96.65	-1.63
	Improved	1	1	3.18	0	68.55	-0.502
	Total	8	8	134.57±23.11	95.23±9.22	29.23	-0.15
Waterguard	Unimproved	9	9	362.69±14.77	56.38±11.35	84.45	-0.81
	Improved	1	1	3	2.45	18.33	-0.09
	Total	10	10	401.40±12.92	66.64±10.50	83.4	-0.78
Ceramic filters	Unimproved	3	3	1373.66±17.63	19.31±168.67	98.59	-1.85
	Improved	7	7	12.21±15.51	1.39±2.38	88.62	-0.94
	Total	10	10	50.36±32.15	3.06±19.31	93.92	-1.22

E. coli/100 ml±SD: *Escherichia coli* concentration±standard deviation; percentage reduction: final concentration minus initial concentration divided by final concentration multiplied by 100; log reduction: difference between pre-treatment and post-treatment log concentration in base$_{10}$

Table 7.3 Average quantity of water consumed by the children below 5 years of age and adults above 18 years of age.

Village	**HWT technology**	**Average quantity of treated water consumed (ml) by child < 5 years**	**Average quantity of treated water consumed(ml) by adult > 18 years**
Angeyoni/Akado	Aquatab	550	1130
Kinasia	PUR	500	964
Kokul	Waterguard	400	1131
Tito	Ceramic filter	375	875
Average quantity for five villages		456	1025

Calculation of the exposure per person per day to water-borne pathogens in drinking water, before and after treatment with selected HWT technologies

Pathogen exposure per person per day was determined using the following formula (van Lieverloo *et al.*, 2007)

$P_{exp.d} = P_{E.d}\ P_{R}\ P_{Cd}$ Equation 1

Where:

- $P_{exp,d}$ = the daily probability density function (PDF) of an inhabitant of the study area being exposed to a pathogen or the expected number of pathogens consumed per person per day
- $P_{E.d}$ = the empirical probability distribution function (PDF) of all *E coli* or TTC concentrations in drinking water during the day
- P_R = empirical PDF of the pathogen (*E. coli* O157:H7) to *E coli* ratios i.e. 1:7 (Enger *et al*., 2012) in the contamination source
- $P_{C.d}$ = PDF of daily consumption of untreated water fitted to a Poisson distribution

The difference in exposure per person per day to water-borne pathogens (using *E. coli* as indicator) when untreated water and treated water was consumed represented the effect of each HWT technology on user-exposure.

Assumptions made in the calculation of the expected number of pathogens consumed per person per day are:

1) That the respondents are exposed to either treated or untreated water whether from an unimproved or improved source.
2) The use of *E. coli* as the indicator microorganism, assumes that every *E. coli* ingested through drinking water constitutes an exposure to *E. coli* O157:H7, irrespective of the virulence of the strain of pathogen and that *E. coli* resistance and infectivity rates are similar to that of *E. coli* O157:H7.
3) That the study population actually consume 1025 ml of water daily.

Although the levels of risk may be higher than if the actual counts of *E. coli* O157:H7 had been used to calculate exposure, the assumptions can be justified with the use of a *E. coli* O157:H7 to *E. coli* ratio, and on the basis that WHO (2008) drinking water guidelines specify the absence of *E.coli* from treated drinking water irrespective of the strain. Furthermore the study aims to assess the difference in risk rather than the prediction of the risk from a specific pathogen .i.e. the difference in probability of infection before use of a technology and after use of a technology.

Calculation of the probability of infection before and after treatment with selected HWT technologies

This study calculated individual risks of infection per contamination event (van Lieverloo *et al.*, 2007) and not a yearly event level of risk in order to minimise effect of uncertainties related to changes in pattern of consumption, pathogen occurrence, and household treatment methods over a longer time frame. The *E. coli* concentration in drinking water collection and storage containers were taken as detected contamination events.

Each value in the PDF of daily exposures was used to calculate the daily probability of infection i.e. the probability that a single exposure to *E. coli* from drinking water consumption will result in infection using the following formula adapted from Abongo *et al.* (2008); van Lieverloo *et al.*(2007).

$$P_{inf.d} = 1 - (1 + d/\beta)^{-\alpha} \qquad \text{Equation 2}$$

Where:

- P*inf.d* = probability of infection risk per person per day
- d = infectious dose = CFU x g capita^{-1} day^{-1} or 1 025 ml person^{-1} day^{-1} based on the average daily intake of water of the study population
- β = Beta model parameter (0.0496)
- α = alpha model parameter 1.001)

The alpha and beta values for *E.coli* O157:H7 were adopted from Abongo *et al.* (2008).

$\text{Pinf.d} = 1 - (1 + d/0.0496)^{-1.001}$

e. The difference in probability of infection before and after treatment was then quantified for each of the four selected HWT technologies, to represent the effect of each technology.

This approach conforms to the use of a prevention of infection approach strategy by the United States Environmental protection agency to reduce risks of enteric diseases associated with water-borne microbial pathogens (USEPA, 1992)

7.3 Results

7.3.1 Exposure per person per day to water-borne pathogens (using *E. coli* as indicator) before and after treatment with selected household water treatment technologies

Table 7.4 shows that the selected HWT technologies, Aquatab, PUR, Waterguard and ceramic filters did not differ statistically in user-exposure to water-borne pathogens if they consumed 1 025 ml of untreated water per person per day from *improved* sources ($p = 0.041$). Aquatab, PUR and Waterguard were similar in user-exposure to water-borne pathogens if they ingested water from *unimproved* sources but differed significantly from ceramic filters users in exposure ($p < 0.04$).

Table 7.4 Test of significance of the mean exposure per person per day of users of selected household water treatment technologies to water-borne pathogens (using *Escherichia coli* as indicator) before and after treatment.

Water source category	**Technology**				**p-value between technologies**
	Aquatab	PUR	Waterguard	Ceramic filter	
Collection unimproved	1.55^{a}±0.75	2.72^{a}±0.69	3.05^{a} ±0.32	3.46^{b}±0.82	***0.04***
Collection improved	2.14±0.24	2.60±1.05	3.16	1.48±1.13	0.41
Storage unimproved	0.23±0.39	1.58±1.39	2.12±0.34	1.64±1.78	0.30
Storage improved	0.51±0.88	1.66±0.77	2.64	1.33±1.43	0.40

Exposure was determined as $\log_{10}$ cfu/1025 ml per person per day; p-value < 0.05 was considered significant at < 0.05 error level and 95% confidence level. Significant difference was established using the Tukey Honestly Significant Difference test. Superscript letters show the relationship between technologies, where similar letters indicates no significant difference and different letters indicates a significant difference.

The four assessed technologies showed a reduction in user-exposure to water-borne pathogens after water treatment. This was demonstrated by comparing the user-exposure before and after treatment with the selected technologies, based on the exposure to water-borne pathogens (using *E. coli* as indicator*)* per person per day of an adult consuming an average of 1 025 ml of water per day from *unimproved* sources (Figure 7.1). Ceramic filters had the highest reduction in user-exposure, even though the users had significantly higher exposure before treatment. In descending order, the mean $\log_{10}$ reduction in exposure to water-borne pathogens ($\log_{10}$ cfu/1025 ml per person per day) was ceramic filter ($\log_{10}$ 1.8) Aquatab ($\log_{10}$ 1.3), PUR ($\log_{10}$ 1.51 and Waterguard ($\log_{10}$ 0.9). Table 7.5 shows that the technologies did not differ significantly in difference in user-exposure (p = 0.83).

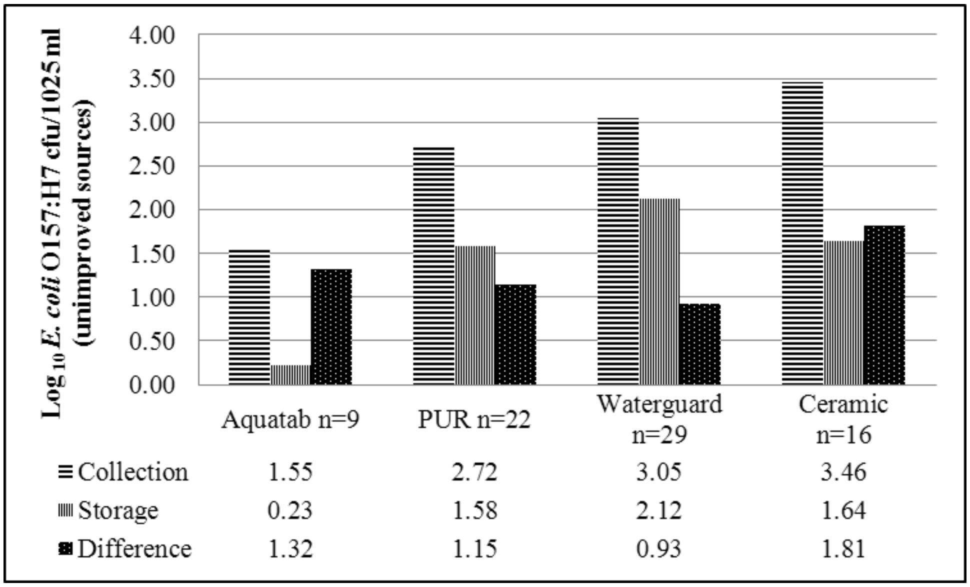


Figure 7.1 Average exposure to water-borne pathogens (using *Escherichia coli*) per person per day and difference in exposure from the consumption of 1025 ml of water per day from *unimproved* sources, before and after household water treatment.

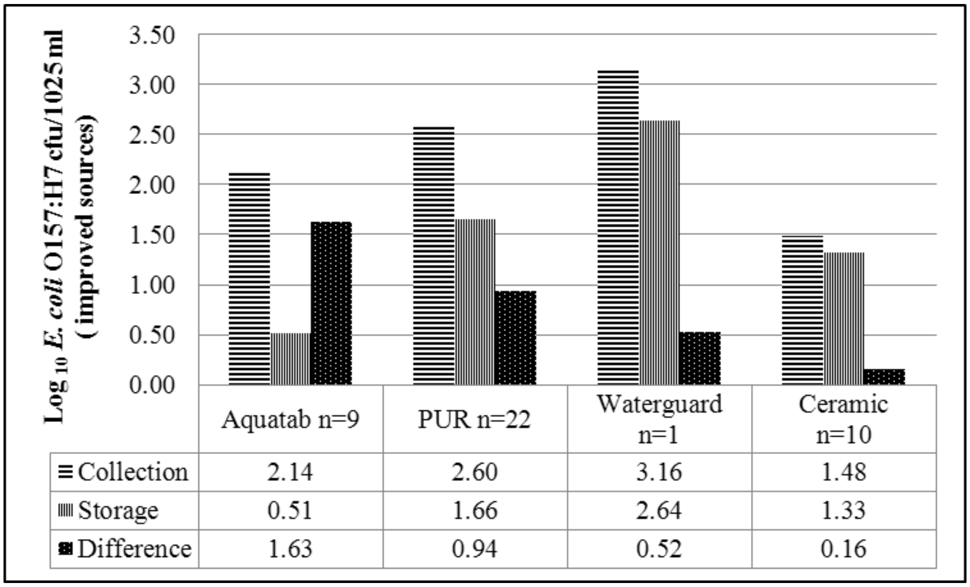
Storage represents after treatment and collection represents before treatment; $\log_{10}$ *E. coli* cfu/1025 ml: Log_{10} *E. coli* colony forming units in 1 025 ml of ingested water.

Table 7.5 Test of significance of mean difference in user-exposure to water-borne pathogens (*Escherichia coli* as indicator) per person per day before and after treatment with the selected household water treatment technologies.

Water source category	**Technology**				**p-value between technologies**
	Aquatab	PUR	Waterguard	Ceramic filter	
Unimproved	1.32	1.15	0.93	1.81	0.83
Improved	1.63	0.94	0.52	0.16	0.60

Significant difference was established using the Tukey Honestly Significant Difference test.

Table 7.5 shows that the HWT technologies did not differ significantly in reduction in user-exposure after treatment of water collected from *improved* sources (p = 0.60). Figure 7.2 shows that when drinking water from improved sources was consumed, the mean difference in exposure to *E. coli* ($\log_{10}$ *E. coli* cfu/1 025 ml of water per person per day) after treatment was Aquatab ($\log_{10}$ 1.6), PUR ($\log_{10}$ 0.9), Waterguard ($\log_{10}$ 0.5) and ceramic filter ($\log_{10}$ 0.16).



	Aquatab n=9	PUR n=22	Waterguard n=1	Ceramic n=10
≡ Collection	2.14	2.60	3.16	1.48
▥ Storage	0.51	1.66	2.64	1.33
▩ Difference	1.63	0.94	0.52	0.16

Figure 7.2 Average exposure to water-borne pathogens per person per day and difference in exposure from the consumption of 1025 ml of water per day from *improved* sources, before and after household water treatment.

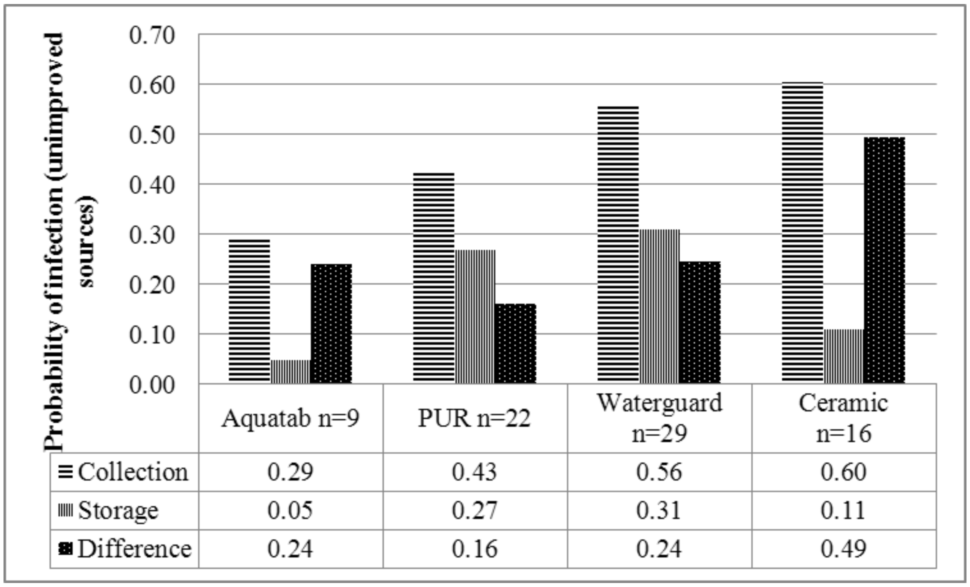
7.3.2 Probability of infection with water-borne pathogens per person per day before and after treatment with selected household water treatment technologies

The technologies did not differ significantly in the average individual risk of water-borne infection of their users before water treatment with the HWT technologies (Table 7.6), thus providing a basis for comparing the probability of infection after household water treatment. This was the case whether the different HWT user households had been exposed to water collected from unimproved (0.10) or improved (0.09) sources (Table 7.6).

Table 7.6 Test of significance of average individual risk of water-borne infection with consumption of 1 025 ml per person per day of untreated drinking water and water treated with the selected household water treatment technologies during the three assessments.

Water source category	**Technology**				**p-value between technologies**
	Aquatab	PUR	Waterguard	Ceramic filter	
Collection unimproved	0.29±0.13	0.43±0.21	0.56±0.08	0.60±0.13	0.10
Collection improved	0.27±0.16	0.59±0.10	0.64	0.22±0.11	0.09
Storage unimproved	0.05±0.08	0.27±0.25	0.31±0.13	0.11±0.12	0.21
Storage improved	0.08^{a}±0.14	0.49^{b}±0.08	0.60^{b}	0.13^{a} ±0.10	***0.04***

When the average individual risk of infection of an individual consuming untreated and treated water from improved and unimproved sources was compared, all the HWT technologies reduced the risk of infection in their users. When the average individual risk of infection of an adult consuming an average of 1 025 ml of water per day from *unimproved* sources was compared before and after treatment with the selected technologies, Figure 7.3 shows that the mean difference in average individual risk of infection before and after treatment was: ceramic filter (0.49), Aquatab (0.24), Waterguard (0.24), PUR (0.16: p = 0.24).



	Aquatab n=9	PUR n=22	Waterguard n=29	Ceramic n=16
≡ Collection	0.29	0.43	0.56	0.60
⦀ Storage	0.05	0.27	0.31	0.11
▩ Difference	0.24	0.16	0.24	0.49

Figure 7.3 Average individual risk of water-borne infection with consumption of 1 025 ml of treated and untreated water from unimproved water sources. Storage is post-treatment.

In descending order, the mean difference in average individual risk of water-borne infection using (*E. coli* as indicator) before and after treatment, in an adult consuming 1 025 ml of treated water per day from improved sources, was: Aquatab (0.19), PUR (0.10) ceramic filter (0.09), and Waterguard (0.05: Figure 7.4). There was no statistical significance to the differences observed between technologies in shift in average individual risk of infection of users after consuming treated water from unimproved (0.24) and improved sources (0.71).

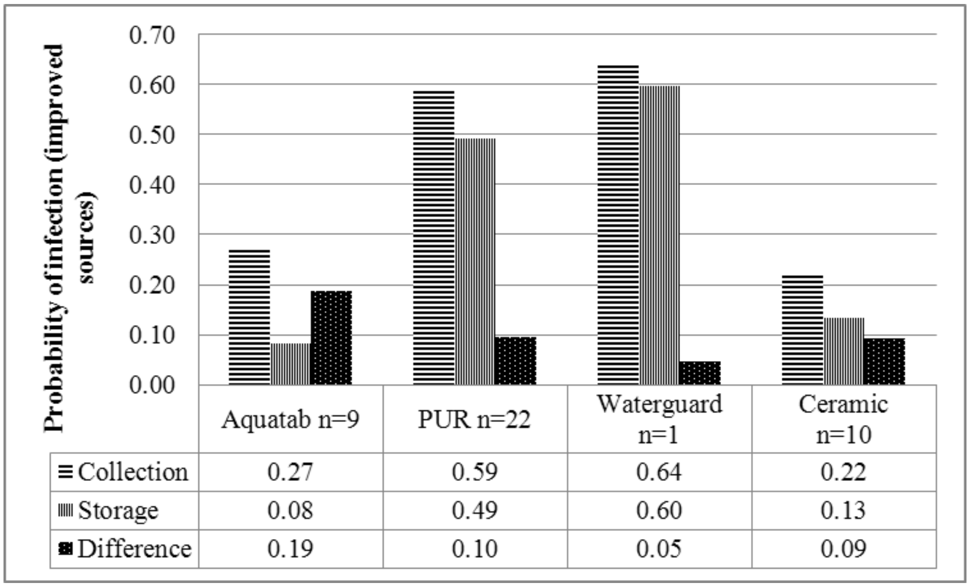


Figure 7.4 Average individual risk of water-borne infection with consumption of 1 025 ml per person per day of treated and untreated water from *improved* water sources. Storage is post-treatment.

Table 7.7 Test of significance of the difference in average probability of infection per person per day after exposure to untreated water and water treated with selected household water treatment after treatment.

Water source category	**Technology**				**p-value between technologies**
	Aquatab	PUR	Waterguard	Ceramic filter	
Unimproved	0.24±0.21	0.16±0.20	0.24±0.17	0.49±0.19	0.24
Improved	0.19±0.09	0.10±0.18	0.05	0.09±0.29	0.71

7.4 Discussion

7.4.1 Effect of household water treatment technologies on exposure to water-borne pathogens per person per day and risk of infection

In spite of the four HWT technologies' inconsistency in effectively decreasing microbial concentrations in treated water to drinking water quality guidelines, the study showed that all the assessed HWT technologies reduced exposure to water-borne pathogens and probability of infection (using *E. coli* as indicator) in users after drinking water treatment. The mean log reduction in exposure to water-borne pathogens in users of the four technologies ranged from $\log_{10}$ 0.9 to $\log_{10}$ 1.8, when they consumed treated water from unimproved water sources (Figure 7.1) and $\log_{10}$ 0.16 to $\log_{10}$ 1.6 when water from improved sources was treated and consumed (Figure 7.2). This translates to a reduction in average individual risk of water-borne infection (using *E. coli* as indicator) ranging from 0.16–0.49 when water from unimproved sources was treated and consumed (Figure 7.3) and 0.05–0.19 when treated water from improved sources was consumed (Figure 7.4). Therefore the study observations do not support the view of Schmidt and Cairncross (2008) that current evidence pointing to the health-related effects of HWT technologies is entirely due to bias.

7.4.2 Comparison of the household water treatment technologies' effect exposure to water-borne pathogens and risk of infection in unimproved water sources

The HWT technologies are compared on the basis of the magnitude of reduction in exposure and risk of infection they achieved after users consumed untreated and treated water from unimproved sources. This is because the study communities and others like them are very dependent on unimproved water sources. Ceramic filters had the highest effect and reduced exposure by 52% (Figure 7.1) and the average individual risk of infection from 6 000 per 10 000 to 1 100 per 10 000 (Figure 7.3). Waterguard had the lowest reduction of exposure in users of 30% (Figure 7.1) and reduced the average individual risk of infection from 5 600 per 10 000 to 3 100 per 10 000 (Figure 7.3). Given that the majority of these unimproved drinking water sources were highly turbid (mean 210.33 NTU±189.30), these findings are again consistent with Sobeys *et al.* (2008) that some hypochlorite-based methods such as Waterguard were not able to perform effectively in turbid conditions, unlike ceramic filters which they considered as robust in their ability to improve the quality of turbid water sources. They also reinforce the warning by Sobsey *et al.* (2009) that hypochlorite-based water treatment methods should not be promoted without adequate measures to ensure that users can reduce the turbidity of the water before disinfection.

By contrast, Aquatab, though a hypochlorite-based method, when compared to Waterguard showed a higher reduction in exposure and reduction in average probability of infection in users.

It was second highest amongst the four HWT technologies in reducing both risk parameters after ceramic filters when water from unimproved sources was treated and consumed (Figures 7.1 and 7.3). This conforms to the findings of Clasen and Edmonson (2005) who observed that Aquatab had a higher level of efficacy over a range of microbes which included *E. coli* and *Salmonella* sp.

PUR acts as both a flocculant and a disinfectant (Lantagne *et al*., 2006); it was therefore expected that the reduced turbidity before treatment, would lead to a higher reduction in exposure to water-borne pathogens and the risk of infection in a user of PUR compared to a Waterguard user. This expectation was confirmed concerning reduction in exposure with both unimproved and improved water sources. A reduction in daily exposure of $\log_{10}$ 1.1 in a consumer of PUR treated water in comparison to $\log_{10}$ 0.9 for the Waterguard user, when unimproved water sources were treated (Figure 7.1), and $\log_{10}$ 0.5 and $\log_{10}$ 0.9 for a Waterguard and PUR user respectively when improved water sources were treated. However, Waterguard had a higher reduction in average individual risk infection (0.24) than PUR (0.16) when unimproved water sources were treated (Figure 7.3), though for improved sources, PUR had a higher reduction in average individual risk of infection in users (0.10) than Waterguard (0.05; Figure 7.4). The lack of consistency and closeness in the magnitude of risk reduction is consistent with the observation by Sobsey *et al.* (2009) that turbidity might mask the actual efficacy of a water treatment method. Rangel *et al*. (2003) in a study in Guatemala observed that Waterguard and a flocculant-disinfectant (PUR) reduced *E. coli* with the same level of efficacy but differed in efficacy in reducing turbidity, with PUR showing a higher reduction than Waterguard.

7.4.3 Comparison of the effect of household water treatment technologies on exposure to water-borne pathogens and risk of infection in unimproved and improved water sources

The reduction in exposure to water-borne infections (using *E. coli* as indicator) and the risk of infection was lower in consumers of HWT-treated water collected from improved sources than HWT treated water from unimproved sources. For instance, the combined reduction in the daily exposure to *E. coli* from treated unimproved water sources was $\log_{10}$ 1.30 compared to $\log_{10}$ 0.81 in the improved water sources, while the combined reduction in probability of infection after the consumption of treated water from unimproved water sources was 0.28 compared to 0.11 after consuming treated water from improved sources. This is consistent with the earlier reported observations in Chapter Five that though the improved sources show a much higher deterioration in quality than the unimproved, the improved sources are less contaminated at every stage than the unimproved sources. It is therefore expected that water of higher quality will result in a lower reduction in risks of exposure and infection. This is consistent with the report by Brown and Clasen (2012) that lower quality water has a higher health risk than water of higher quality and the health impact of HWT is greater where poorer quality water is used.

In terms of individual technologies, ceramic filters showed the greatest contrast between improved and unimproved sources with the highest reduction in exposure to *E. coli* ($\log_{10}$ 1.8) of the four technologies, when treated water from unimproved water sources was consumed (Figure 7.1), but the lowest ($\log_{10}$ 0.16) when water from improved water sources was treated and consumed (Figure 7.2). Similarly, the reduction in average risk of infection when a ceramic filter user consumed treated water from unimproved sources (Figure 7.3) was almost five and half times the reduction in average risk of infection when the consumed treated water was from improved water sources (Figure 7.4).

Though the reduction in exposure and risk is expected to be lower because of the better quality of improved water, study findings can also be attributed to the consumers of water from improved sources possibly engaging in risky behavior by omitting to take the necessary steps to protect their drinking water (Wright *et al.*, 2004), while those who take water from unimproved water sources may take more precautions (Brown and Clasen, 2012). Brown and Clasen (2012) queried the role that perception of water safety plays in user adherence and health risk. This study found that households perceived rainwater as an improved source which did not require treatment, though rainwater used by the study households was found to be contaminated with *E. coli*.

The observation in this study of an average individual risk of infection of 47% (range 29%–60%) for the four HWT technologies with the daily consumption of untreated water from unimproved sources is consistent with the probable risk of infection of 11%–59% reported by Genthe *et al.* (2011) for water-borne pathogens when untreated surface water was ingested in a

South African study. The average individual risk of water-borne infection observed in this study and that of Genthe *et al.* (2011) was higher than those observed by Steyn *et al.* (2004), who reported a probable risk of infection of 1.88% with a single exposure to 100 ml of recreational surface water in a South African study. The average individual risk of infection was however lower than that of Abongo *et al.* (2008) who found a higher individual risk of 75% to 81% for *E. coli* O157:H7 after a single exposure to 1 500 ml of water from public standpipes in informal settlements in South Africa.

The differences in probabilities of infection obtained by the studies can be attributed to the use of different beta and alpha parameters by the different studies, the use of risk models previously used from studies outside Africa, as well as the differences in the manner of determining exposure (Abongo *et al.*, 2008; Steyn *et al*., 2004). Genthe *et al.* (2011) estimated exposure to surface water sources and assumed an ingested amount of 100 ml per event, while this study determined exposure to untreated unimproved and improved sources on the basis of the consumption of 1025 ml per day. Genthe *et al.* (2011) noted that the estimates used in their risk model were conservative and actual risks of infection would be considerably higher.

The objective of this study was not to assess actual levels of risk but the shift in risk of infection to users of household water treatment. Notwithstanding the similarities or differences in estimates of probable infection risks with other studies, this study indicates that HWT methods reduced the average individual risk of infection per person per day for water-borne pathogens from 47% (range 29%–60%) to 19% (0.05%–0.31%) after consumption of treated water from unimproved sources. However, the risk after treatment was still higher than the acceptable annual risk of infection from enteric diseases of 1 in 10 000 people (USEPA, 1989) which reinforces the importance of improving the effectiveness of the assessed HWT products in typical-use situations.

7.5 Conclusion

This study found that, in spite of the inability of the HWT technologies to achieve a *protective* level of performance as defined by the WHO (2011) in a post-implementation and real-world setting, the HWT technologies reduced the user's exposure to water-borne pathogens (using *E. coli* as indicator) and probability of infection when unimproved and improved water sources were treated and consumed. This suggests that though they are not perfect, HWT technologies provide some level of protection and health benefit to the consumer. While it is recognised that many classes of pathogens found in faeces are able to cause water-borne infections (Leclerc *et al.*, 2002) and that apart from exposure, other factors such as virulence, infectivity, individual immunity determine the probability of infection with water-borne diseases (WHO, 2008), this study's findings provide a preliminary basis for decision-making about the promotion of HWT technologies.

The study findings lend support to two alternate scenarios: The first is discontinuing the large-scale HWT technology promotion based on the observation that though HWT technologies reduce the risks of infection, they do not do so consistently to a point where HWT-treated water can be considered as holding negligible risks of exposure and infection to the consumer. The second is continuing HWT promotion, based on the study's observation of reduced exposure to water-borne pathogens and risk of infection in consumers of HWT-treated water, since these users would otherwise be fully exposed to the health risks of consuming untreated water from polluted sources.

This author supports a third scenario, suggested by Sobsey *et al.* (2009), that HWT technologies should be promoted with an urgent call for the appropriate guidelines and supportive technology to help the users of HWT improve the effectiveness of HWT technologies. This study's findings on KAP and HWT adoption will help with the development of such guidelines.

8 CONCLUSION AND RECOMMENDATIONS

The conclusion and recommendations of this multi-lens study which examined various aspects of household water treatment are presented in this section.

8.1 Conclusion

The knowledge, attitudes and practices (KAP) study (Chapter 3, Table 8.1) provided contextual evidence of the knowledge, attitudes and practices of the study communities which may affect HWT effectiveness one to two years after the end of the HWT intervention. It showed that the intervention (IG) and control group (CG) had unhygienic KAP even though HWT was introduced to the IG through an HWT promotion program. Examples of these KAP include the predominant use of surface water and poorly harvested rainwater for drinking, a poor knowledge of contamination routes and barriers to water-borne diseases, as well as the inadequate practice of hand-washing with soap after faecal contact. Though these unhygienic KAP make the use of household water treatment methods advisable for reducing exposure to water-borne pathogens. However, the same KAP which makes HWT necessary in these communities and others like them makes it unlikely that they will use the HWT technologies effectively or reduce microbial concentrations to the level achieved when household water treatment technologies are used by proficient operators.

A household water treatment adoption survey (Chapter 4, Table 8.1) was conducted to assess the perceived value the intervention and control communities attach to HWT as well as their likelihood of adoption and compliance. This provided insight into HWT-related user-behaviour which may affect the effectiveness of the HWT technologies. The HWT's adoption survey showed that the intervention and control communities attached a high value to the HWT methods and perceived HWT as a very good practice and the methods to be effective against germs and diarrhoea. However, the value attached to the HWT products differed in terms of real-world related criteria such as time taken to use, the ease of obtaining them, and their ability to use them, with some products being perceived as high value and others low. Thus, though households may believe a method is good and effective against diarrhoea, adopting a method and sustaining it will be influenced by their perception of its affordability, ease of use, and ease of obtaining the product. Furthermore, poor storage practices and poor knowledge of how to use the products correctly will not only reduce the effectiveness of these HWT methods in a real-world context, but will constitute a danger to the health of such consumers.

Determining the drinking water quality of sources used by the study communities (Chapter 5) reinforced the importance of effective household water treatment, because of the poor microbiological and physico-chemical quality of the study households' improved and unimproved drinking water sources. Their major source of improved water, rainwater, was faecally contaminated, though other improved sources like the motorized and handpump-fitted boreholes were not.

The levels of turbidity, nitrates, manganese, lead and aluminium of some of the drinking water sources used in the communities exceeded the levels recommended in the drinking water guidelines. Consequently to protect the health of users of HWT, it is important to address the physical and chemical quality of drinking water, because tracking the changes in microbiological quality from source to point-of-use (Chapter 5) had already reinforced the importance of effective household water treatment. In spite of the high quality of some of the improved sources at the source, the improved water sources deteriorated in quality between source and collection and became more faecally contaminated, while the unimproved sources improved in quality, though they did not comply with the drinking water guidelines. Both categories however, improved in quality between the collection and storage points, coinciding with the point at which HWT products would normally be applied. The highest level of faecal contamination in the improved and unimproved sources was between source and collection, and the lowest level between collection and storage. Though the improved sources had a higher level of deterioration than the unimproved sources, the improved sources were of better quality than the unimproved sources at every stage of assessment: source, collection and storage, reinforcing the importance of increasing access to improved water sources.

Assessing the relationship between KAP and drinking water quality (Chapter 5, Table 8.1) showed that, in this high-risk setting of poor KAP, poor HWT user-behaviour and poor local water quality, some household practices were predictors of the microbiological quality of stored water: source water category and mouth-type of storage container. Other household related variables, such as storage practices, sanitation category, hygiene practices, and under-five sanitation practices, were not predictive of stored water quality.

The importance of HWT, even under real-world uncontrolled conditions, was highlighted by the findings in Chapter 5 (Table 8.1) that, in spite of the hygienic or non-hygienic nature of the KAP of the households, in 22 out of 38 KAP variables, active household water treaters had better quality of water in their storage containers than inactive water treaters. Household water treatment was statistically predictive of the water quality in four of the 38 variables examined.

The assessment of the post-implementation effectiveness of selected HWT technologies under real-world conditions (Chapter 6, Table 8.1) showed reduced effectiveness compared to what would be expected under more controlled laboratory or field trial conditions. Generally, all four technologies were inconsistent in their effectiveness and none had a highly protective or even protective level of performance in the study circumstances. Though the percentage of samples that complied with the drinking water guidelines for *E. coli* increased after treatment with each of the technologies, none of the technologies attained the baseline log reduction value compliance in all the three assessments. Ceramic filters recorded the highest mean percentage compliance but did not attain the baseline log reduction value in most of the assessments. Furthermore, the HWT technologies' inconsistent performance was highlighted by their inability after treatment to increase the percentage of samples that complied with the drinking water guidelines for total coliforms in most of the assessments. There was no significant difference between technologies in their performance in increasing the percentage of samples that complied with both *E. coli* and total coliform drinking water guidelines. Similarly, there was no significant difference between the four technologies in their reduction of *E. coli* concentrations. Although the difference in performance between the four technologies was not statistically significant, PUR performed better than Waterguard in treating water from unimproved sources, with Waterguard showing an increase in *E. coli* count in one of the three assessments, while PUR reduced the *E. coli* count to zero in one of the three assessments. The Quantitative Microbial Risk Assessment (Chapter 7, Table 8.1) indicated that all the HWT methods reduced users' exposure to water-borne pathogens after treatment with each of the technologies, though there was no significant difference between technologies in the levels of reduction in exposure.

Table 8.1 Building a Case (BaC) of evidence of causes of HWT technologies ineffectiveness, post-implementation using a conceptual framework (Suter and Cormier, 2011).

Overall study hypothesis	Chapter and objective	Body of Evidence from study key findings	Body of Evidence from literature	*Weight of Evidence	Type of and overall contribution to study aim
Household water treatment (HWT) technologies are not used effectively by households in rural Kenya after the HWT implementation period. **Supporting literature:**"Effectiveness = efficacy and KAP factors and perceived value of HWT and likelihood of adoption and compliance" (Mclaughlin *et. al.* , 2009)	Assess water, sanitation and hygiene (WASH) related knowledge, attitudes and practices (KAP) of the study households (Ch. 1)	1) 1 in 2 households use improved water sources in IG and CG; 2) 1 in 10 own improved sanitation facilities in IG and CG; 3) Poor knowledge of barriers to contamination (52.39%: IG & 58.44%: CG) & poor fecally related handwashing practices in both IG (29.22% and CG (20.78%).	Inadequate access to safe water, poor sanitation or unsafe defecation practices affect water handling from source to the point of use in the household and impact on drinking water quality. (Roberts *et al* ., 2001; Wright *et al* ., 2004; Trevett *et al.*, 2005; Galiani and Orsola-Vidal, 2010). "Microbial log reduction value of HWT is lower than typically expected when operators lack skill and support" (Sobsey *et al* ., 2008; WHO, 2008).	+++	The water, sanitation and hygiene knowledge and practices of the IG and CG are ***joint proximate*** causes of user ineffectiveness of HWT technologies, because the study findings suggest that such users will be unable to operate the technologies effectively
	Investigate the perceived value attached to HWT technologies and the likelihood of the adoption of and compliance with HWT technologies (Ch. 2).	1) IG & CG attached high perceived value to all assessed HWT. However the likelihood of compliance was lower than the likelihood of adoption. 1a) Ceramic filter (IG) : adoption (92%); compliance: sustained use (77.5%) + correct use (0%) + user likes (12.5%); 1b) Waterguard (IG) : adoption (82%%); compliance: sustained use (77.5%) + correct use (40%) + user likes (25%). 1c) Aquatab (IG) :adoption (75%); compliance: sustained use (72.5%) + (30%) + user likes (27.5%); 1d) PUR (IG) : adoption (69%); compliance: sustained use (67.5%) + (40%) + user likes (27.5%)	"Effectiveness of an intervention is a measure of the levels of its adoption and its sustainability" (Waddington *et al* ., 2009); "Technical, social and financial behavioural factors influence the adoption of and compliance with HWT technologies" (deWilde *et al.* , 2008; Luby *et al* ., 2008; Meierhofer and Landolt, 2008; Stevenson, 2008; Holla and Kremer, 2009; Kraemer and Mosler, 2010).	+++	The likelihood of adoption is discarded as a cause of poor HWT effectiveness because percieved value is high, but likelihood of compliance is established as a ***proximate cause*** to HWT ineffective, post-implementation.
	Assess the changes in microbiological water quality from source to point-of-use and the correlation between the WASH knowledge, attitudes and practices (KAP) of user households and observed levels of water quality (Ch. 3).	1) Improved and unimproved sources fecally contaminated (geometric mean *E. coli* load improved: 5.71±8.69 cfu/100 ml; unimproved: 296.67±129.35 cfu/100 ml); 2) Deterioration in microbiological water quality after collection, though improved sources had lower mean *E. coli* load at source: p=001; collection: p=0.0001 and storage: p=0.004; 3) Stage of greatest *E. coli/100 ml* contamination : between the source and collection points for both improved (-22.67% difference) and unimproved sources (-2.81% difference); 4) Main source of water during rainy season was rainwater and 35.7% of samples non compliant, 5) KAP: Source water category & mouth type of storage container positively associated with stored water quality	"Technology selection cannot be completed in isolation from consumer preference, economic considerations, cultural practices, and ***local water quality"*** (Sobsey *et al* .,2009)	+++	The poor microbiological quality of the source water is established as a ***dominant cause*** of the need for HWT in the intervention community and a ***proximate cause*** of the inability of the HWT technologies to attain sector performance standards
	Assessment of the effectiveness of selected HWT technologies during the post-implementation period (Ch. 4).	1) All assessed technologies reduced *E. coli* counts in treated water. e.g. ranking & mean log reduction in combined sources: AT (1st, 1.49); PUR (2nd, 0.78); WG (3rd, 0.54); CF (4th, 0.04). 2) All HWT performed below sector standards. 2a) Robustness: Ranking and mean log reduction in unimproved sources: PUR (1st, 2); CF (2nd, 1.57); Aquatab (3rd, 1.06);WG (4th, 0.44). 2b) Consistency: ranking and number of compliant mean log reductions in total assessments: Aquatab (1st, 4 in 9); PUR (2nd, 2 in 8); CF (3rd, 1 in 8); WG (4th, 0 in 8).	" Arguably, effectiveness is a more accurate description of how chlorine use will affect health, suggesting that variables such as ease of use and uncontrolled water quality parameters may prove to be important factors in assessing point-of-use drinking water treatment" (Mclauglin *et al* ., 2009).	+++	The inconsistent performance, inadequate robustness and below baseline microbial log reduction of HWT are ***direct causes*** of the findings of performance below stipulated sector standards.
	Assessment of the change in risk of bacterial waterborne infections in users of selected HWT technologies, using *E. coli* as an indicator (Ch. 5).	1) All HWT reduced exposure to waterborne pathogens. e.g ranking & mean log reduction in exposure in unimproved sources: CF (1st, $\log_{10}$ 2.1); AT (2nd, $\log_{10}$ 1.9); PUR (3rd, $\log_{10}$, 1.5); WG (4th, $\log_{10}$,0.9). 2) All HWT reduced risk of water-borne infection. 2a) Difference in risk of infection after treatment in unimproved: CF (1st, 0.22); AT (2nd, 0.11); WG (2nd, 0.11); PUR (4th, 0.07). 2b) In improved: AT(1st, 0.08); CF (2nd, 0.04); PUR (2nd, 0.04); WG (4th, 0.02)/ 3a) Reduction in risk of infection was below recommended USEPA level	"However, concerns have been raised about the possible bias of these intervention studies and changes in efficacy of HWT over time, which may negate the suggested health benefits" (Schmidt and Cairncross, 2008; Mclaughlin *et. al* ., 2009) and affect investment decisions and scaling up HWT.	+++	HWT has potential health benefits even within post-implementation period

*Causal Analysis Diagnosis Decision Information System (CADDIS): +++ or ---convincingly supports or weakens findings, ++ or- strongly supports or weakens, + or - somewhat supports or weakens.

The technologies reduced the probability of infection by bacterial water-borne pathogens in users when treated water from both improved and unimproved water sources was consumed, though the degree of reduction in risk was higher with ingestion of treated unimproved water sources than from improved sources. This suggests that the health benefits of household water treatment may be more pronounced in water sources that have higher levels of microbial contamination before treatment, because of the comparatively higher degree of reduction in exposure and attendant probability of infection. The reduction in probability of exposure after the consumption of treated water from an unimproved source was lowest with Waterguard and highest with ceramic filters, suggesting that the efficacy and health benefits of Waterguard, in particular, are compromised by high turbidity.

Though the four HWT products reduced the probability of infection with *E. coli*, the risk to the user after treatment with each of the HWT products was still much higher than the acceptable annual risk stipulated by the USEPA. This is not surprising because though the study households generally perceived the HWT technologies as high value products, they were unable to use them correctly.

In bringing together the various lenses used by the study, a process of "Building a Case" (Suter and Cormier, 2011) was used. During the post-implementation period, the KAP of the study communities suggested that they needed HWT but their KAP would be joint proximate causes of an inability to use HWT technologies **effectively** (Chapter 3, Figure 8.1) and poor microbiological drinking water quality at the point-of-use (POU)(Chapter 3, Figure 8.1). The lower likelihood of compliance of HWT technologies compared to the likelihood of adoption also suggested potentially poor drinking water quality (POU) in both the IG and CG and an ineffective use of HWT (Chapter 4, Figure 8.1). A proximate cause of the ineffectiveness of HWT after the implementation period is the poor quality of both improved and unimproved sources used by the study communities and the deterioration after collection (Chapter 5, Figure 8.1). Consequently, the inconsistency of the technologies in attaining sector standards and their inadequate robustness in improving the quality of the treated water are direct causes of the findings of HWT ineffectiveness, post-implementation (Chapter 6, Figure 8.1). The below sector standards performance of the HWT technologies had the effect of improving the water quality after treatment and reducing user exposure to water-borne pathogens and risk of infection.

However the risk of infection was still higher than the USEPA stipulated accepted annual risk of infection of enteric pathogens (Chapter 7, Figure 8.1).

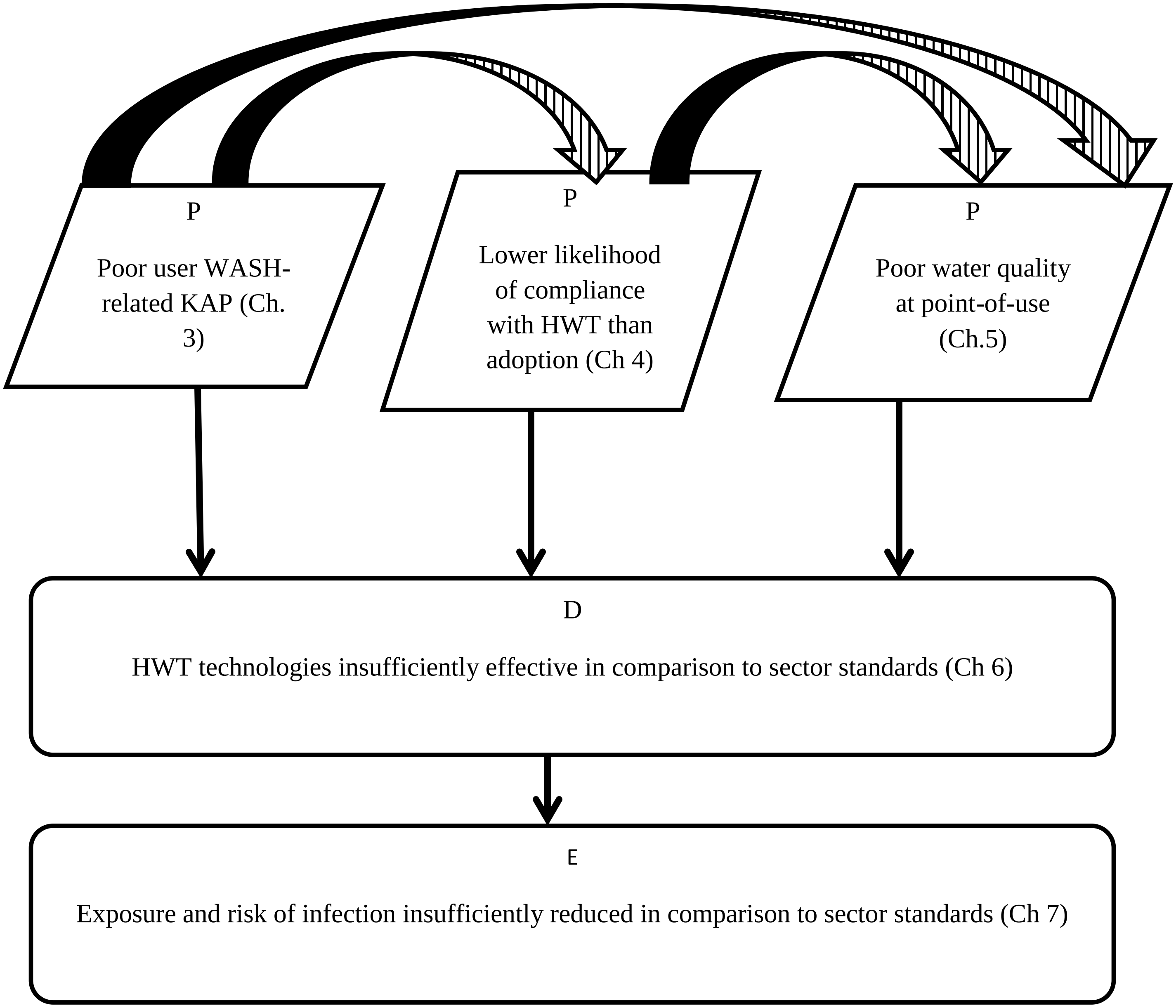


Figure 8.1 Conceptual model for contributors to below sector standard effectiveness of HWT technologies — post-implementation. P: proximate cause converted to intermediate cause, D: direct cause, E: Effect; patterned arrows indicate influence, block arrows indicate causal relationship (Suter and Cormier, 2011).

Given the above and considering that the efficacy of the four household water treatment methods have been proven in some controlled laboratory and short-term field trials, it is reasonable to conclude that human-related behavioural factors reduced the efficacy of the HWT technologies to below the expected baseline log reduction values.

The use of a quasi-experimental design for two of the five study objectives allowed the generalization of the findings beyond communities in which HWT has been promoted and prevented biases related to the absence of controls, while the use of an observational design for the other four study objectives eliminated the biases which arise in case-control studies because of the different information given to treatment (cases) and non-treatment (control) groups.

A limitation of this study was the difference in the number of samples from improved and unimproved water sources used to assess the performance of the technologies. For example households using Waterguard used mostly unimproved sources. These differences could not be avoided as these were the sources used by the study households and the aim of the study was to assess effectiveness within a real-world context. Potential biases related to this were minimised by stratifying analysis according to water source category when testing the significant differences in microbial quality, exposure and probability of infection of the water sources used to assess the different HWT methods.

Another study limitation was its reliance on self-reporting of household treatment to address the study objective of evaluating the HWT methods. However, steps were taken to minimize any potential bias due to misclassification of type of treatment. The steps taken were validation of the self-reports by sighting the HWT technologies (during the adoption and KAP surveys), chlorine residual testing (during the adoption survey) and administration of questionnaires at six out of the eight stages of the study (including this stage). The validation showed a consistency in the households' reporting about the type of water treatment they used and the self-reported products were sighted in most of the households.

8.2 Recommendations

Based on the study findings, the following recommendations are made to the drinking water supply and sanitation sector:

1) Integration of HWT promotion with sanitation and hygiene promotion with an increased focus on user-awareness of contamination routes and barriers, the role of household water

treatment in disease prevention, under-five sanitation practices, the importance of hand-washing with soap after faecal contact and appropriate water storage practices.

2) Education of communities on the critical steps for effective household water treatment use, and selection of household water treatment methods that will meet the three most frequently mentioned expectations of safe drinking water: visual clarity, absence of germs, and the taste of drinking water.
3) Scale up adoption of and compliance with HWT by ensuring that HWT program designs address the factors that users attach low values to, for example, the ease of accessing ceramic filters.
4) Provision of improved water sources as the first step towards protecting the health of users, and enforcement of adherence by practitioners to the stipulated standards for development of these water sources.
5) Revision of the classification of rainwater as an improved source, because the implied perception of safety encourages users not to take protective measures to treat rainwater with negative consequences for their health.
6) Implementation of short-term measures to enable users to select appropriate HWT technologies to treat highly turbid water and long-term measures to develop simple tools to assist households to determine the turbidity levels of their water sources.
7) Revision of the design of HWT technologies by addressing the aspects that make users perceive them as low-value products.
8) Identification and promotion of low-cost HWT technologies which address chemical as well as microbiological water quality in the rural areas and more studies on chemical pollution of drinking water sources in rural areas.

There will be significant public health benefits if the effectiveness of HWT methods is improved by addressing behavioural factors that decrease adoption and sustained use, such as improving aspects of the technologies that users attach low values to, educating users in correct HWT use, informed selection of technologies, and raising awareness about the use of HWT, not only in disease prevention, but also as a means of improving the aesthetics of the drinking water source.

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ANNEXURE FOR ABSTRACT

Appendix 1.1 Synopsis: Chapters 3 and 4.

Chapter	Research Question	Objective	Basis of comparison	Statistical analysis & variables	Results	Specific conclusions	Overall contribution
3	What are the KAP of the study communities in relation to water, sanitation and hygiene, and how are these related to the effective household water treatment?	Assessment of water, sanitation and hygiene (WASH) related knowledge, attitudes and practices of the study households	Intervention (IG) and Control group (CG)	Descriptive statistics (means, standard deviation, fishers exact and chi square test of association, odds ratio)	1 in 10 households use improved water sources in IG and CG; rainwater major drinking water source in rainy season	1. Poor access to adequate sanitation and safe water	1. KAP of both IG and CG indicate that they need HWT, but suggests that they will be unable to use ; technologies effectively
					1 in 10 households use improved water sources in IG and CG; NS; rainwater major drinking water , source in rainy season; NS	2. Poor handwashing at fecally related critical time	2. potential indication of poor treated water quality, particularly in a post-implementation period when support has been removed
					1 in 10 own improved sanitation facilities in IG and CG; NS	3. Poor knowledge of contamination routes and barriers	
					Poor knowledge of barriers to contamination (52.39% IG & 58.44% CG) & poor fecally related handwashing practices in both IG (29.22% and CG (20.78%); NS	4. No significant difference between IG and CG in terms of 18 of 20 socio-economic variables	
4	What is the likelihood of adopting and complying with HWT technologies based on the perceived value households attach to the technologies?	Investigation of the perceived value attached to HWT technologies and the likelihood of the adoption of and compliance with household water treatment technologies	Intervention (IG) and Control group (CG)	Descriptive statistics and multivariate logistic regression	Ceramic filter (IG) :likelihood of use : **Likely**; Highest perceived value overall (67.9%); adoption (92%)+ sustained use (77.5%) + (0%) +user likes (12.5%)	High perceived value attached to HWT (IG and CG)	1. High perceived value is attached to HWT by IG and CG, and likelihood of adoption of the technologies very high - high.
					Waterguard (IG):likelihood of use : **Likely**; 2nd highest perceived value overall (66.8%) ; adoption (82%)+ sustained use (77.5%) + (40%) +user likes (25%)	Likelihood of compliance lower than likelihood of adoption	2. Poor likelihood of compliance suggests potential inability to use HWT effectively and potentially poor treated drinking water quality . Particularly in a post-implementation period when no external support provided
					Aquatab (IG) :likelihood of use : **Likely**; 3rd highest perceived value overall (62.1%) ; adoption (75%)+ sustained use (72.5%) + (30%) +user likes (27.5%)	Similar perceived values, likelihood of adoption and compliance in IG and CG	
					PUR (IG):likelihood of use : Fairly **likely**; 4th highest perceived value overall (58.4%) ; adoption (69%)+ sustained use (67.5%) + (40%) +user likes (27.5%)		

Appendix 1.2 Synopsis: Chapters 5 and 6.

Chapter	Research Question	Objective	Basis of comparison	Statistical analysis & variables	Results	Specific conclusions	Overall contribution
5	What are the changes in microbial quality of drinking water if any, from source to point-of-use, at which stage is water recontaminated, and how is the observed stored water quality related to knowledge, attitudes and practices?	Assessment of microbiological water quality changes from source to point-of-use (POU) and the correlation between the (WASH) knowledge, attitudes and practices (KAP) of user households, service providers and observed levels of water quality	1. Improved and improved sources	Geometric means and standard deviation; analysis of variance (one way ANOVAs) and post-hoc test of significance	Improved and improved sources fecally contaminated (geometric mean *E. coli* load improved: 5.71±8.69 cfu/100 ml; unimproved: 296.67±129.35 cfu/100 ml for the improved and unimproved sources respectively.	Poor water quality in study communities	1. Study communities and others like them need HWT, particularly because their main water source i.e. rainwater is of poor quality
			2. Active treater and inactive treater	Multivariate logistic regression	Rainwater fecally contaminated improved source. 35.7% of samples non compliant	Rainwater quality poor	2. KAP impacts negatively on water quality, nevertheless HWT improves water quality even in a post-implementation period
				odds ratio	Deterioration in microbiological water quality after collection; improved source samples also had a lower geometric mean load than unimproved sources for both total coliform and *E. coli* at all critical points (source: p=001; collection: p=0.0001; storage: p=0.004	Water deteriorates in quality in both improved and unimproved sources but quality better in unimproved at all critical points	
					Stage of greatest E. coli/100 ml contamination : between the source and collection points for both improved (-22.67% difference) and unimproved sources (-2.81% difference)	Lowest contamination point coincides with point at which HWT would usually be applied; suggesting a positive effect of HWT even in under the less than ideal conditions	
					lowest stage of E. coli contamination : between collection and storage for both improved. % increase in compliant samples (2.22%) and unimproved sources (20%)	KAP affects water quality	
					Source water category & mouth type of storage container positively associated with stored water quality	HWT has an effect even under the less than ideal conditions	
					Active treaters had higher stored water quality than inactive treaters in 22 of 38 KAP variables; 4 were statistically significant		
6	How effective are the selected household water treatment technologies after the promotion/trial period within the intervention and control communities?	Assessment of the effectiveness of selected household water treatment technologies in a post-implementation period	Intervention group: improved and unimproved water sources	Log reductions, percentage reductions and Post - hoc Turkey tests of significance	1. All assessed technologies reduced *E. coli* counts in treated water; no significant difference	All HWT technologies improved water quality. No significant difference, Aquatab treated combined sources most effectively, was most consistent in performance & PUR performed best in unimproved water sources	All HWT technologies improved water quality in post-implementation period but performed below stipulated sector standards
					1 a) Ranking & mean log reduction: in combined sources: AT (1st, 1.49); PUR (2nd, 0.78); WG (3rd, 0.54); CF (4th, 0.04)		
					2 Performance below sector standards		
					2a) Robustness (effective treatment of water sources unimproved water sources):		
					PUR (1st, 2); CF (2nd, 1.57); Aquatab (3rd, 1.06);WG (4th, 0.44) N.S		
					2b) Consistency ranking of total assessments: Aquatab (1st, 4 in 9); PUR (2nd, 2 in 8); CF (3rd, 1 in 8); WG (4th, 0 in 8)		

Appendix 1.3 Synopsis: Chapter 7.

Chapter	Research Question	Objective	Basis of comparison	Statistical analysis & variables	Results	Specific conclusions	Overall contribution
7	What is the effect of the selected HWT technologies on the risk of waterborne infections using *E. coli* as an indicator	Assessment of the change in risk of bacterial waterborne infections in users of selected household water treatment technologies, using *E. coli* as an indicator	Intervention group: unimproved and improved water sources	Log reductions, probability distributions and Post - hoc Turkey tests of significance	1) All HWT reduced exposure to bacterial water borne pathogens	All HWT technologies reduced exposure and risk of infection but did not attain sector guideline levels	HWT has potential health benefits even within post-implementation period
					1a) ranking and mean log reduction in exposure; unimproved: CF (1st, log $_{10}$ 2.1); AT (2nd, log 10 1.9); PUR (3rd, log 10 1.5); WG (4th, log 10,0.9)		
					1b) Ranking and mean log reduction in Improved: AT (1st, log $_{10,}$ 2.2); PUR(2nd, log 10 1.5); WG (3rd, log 10 0.5); CF (4th, log 10,0.1)		
					2 All HWT reduced risk of bacterial pathogen water-borne infection		
					2a) Before and after treatment difference in risk; unimproved: CF (1st, 0.22); AT (2nd, 0.11); WG (2nd, 0.11); PUR (4th, 0.07)		
					2b) Improved: AT(1st, 0.08); CF (2nd, 0.04); PUR (2nd, 0.04); WG (4th, 0.02)		
					3a) Reduction of risk infection below USEPA level		
					average individual risk of infection probability of infection per person per day for bacterial water-borne pathogens from 21% (range 7%–22%) to 8% (2%–14%) after consumption of treated water from unimproved sources versus USEPA acceptable annual risk of 1 in 10 000 people		

ANNEXURE FOR CHAPTER THREE: KAP SURVEY

Appendix 3.1 Questionnaire for Community's Water, Sanitation and Hygiene Knowledge, Attitudes and Practices Study

Serial Number: /___/___/___/___/___/___/___/___/

INTRODUCTION AND INFORMED CONSENT

READ INFORMED CONSENT FORM

Sir/Madam, My name is ____. We are conducting a survey on Water and Sanitation, knowledge, attitude and practices. We would value and appreciate your participation in this exercise. The survey may take about 40 minutes. Whatever information you provide will be strictly confidential and will help you understand how to keep your drinking water safe. Participation in this survey is voluntary, and non participation attracts no penalty, though we hope that you will participate since your views are important and will help households make their water safe.

At this time do you want to ask me anything about the survey? |Yes|___| |No|___|

May I begin the interview now? |Yes|___| |No|___|

IF RESPONDENT AGREES TO BE INTERVIEWED............................START

IF RESPONDENT DOES NOT AGREE TO BE INTERVIEWED ......END PROCESS

Date of interview: (DD/MM/YYYY) |__|__|/|__|__|/|__|__|__|__|

Interviewer ID/Name: |__|__|__| /______________________________

Signature of Interviewer: __________________________________

Time started: :

		NAME	CODE	
1.	State/Province			
2.	District			
3.	Division			
4.	Location			
5.	Sub-location			
6.	Village			
7.	Household	N/A		
8.	Respondent – Male/Female care giver of youngest child in the house.	N/A	Gender: /M/ /F/	

SECTION A: GPS

1. GPS location of compound: N |__|__| ′ |__|__|. |__|__|__| E|__|__|__| ′ |__|__|. |__|__|__|
2. (a) Elevation |_______|m (b) Accuracy |_______|m
(c) GPS Waypoint # |_______| (d) GPSID |__| |__|__|

Tick appropriate option

Community: Urban ……………..… (More than 20,000 people)

Small town……..........................…. (Between 5,000 and 20,000 people)

Rural……………......................…. (Less than 5,000 people)

1. **SECTION B:**	How long have **you** personally been	Years			
2.	How long has your household been living continuously in this	Years			
3.	How old were you at your last birthday?	Age in completed year			
4.	Marital Status.	Code: ______________________			
5. .	How many times do you leave this community for at least more than 4 hours?	Code: ________________________			
6. .	How many people live in your household? (Note that you some ages will fall into more than one category e.g. 16 fill all that apply)	***Category***	***Male***	***Female***	***Total***
		Under 1			
		1 – <5 years			
		5 – 14 years			
		15 - 19 years			
		15 – 30 years			
		15 – 64 years			
		65+			
7.	How old is the youngest child in your house? (Record completed years using 2 digits. If under 1 year, code ’00’. If 95 years and above code ’94’)	Years			
8. .	What is your mother tongue?	Code _________			
9. .	Which other Languages do you speak? Multiple Responses	CodeS: Any other specify:_______________(97)			
10.	What is your religion?	Code: _______Any other specify:_______________(97)			
11. .	What is your position in this household?	Code: __________________ Any other specify:_______________(97)			
12. .	What is your main	Code: __________________ Any other specify:_______________(97)			

13. .	What is the gender of the head of the household?	Code: ___________________
14. .	What is the occupational status of the head of the household?	Code: _________________ Any other specify: (97)
15. .	What is the highest level of education you have?	Code: _______________
16. .	What is the highest level of education the head of household have?	Code: _____________
17. .	**Household head membership**	**Yes** | **1** | **No** | **2** | **Don't know** | **98**
	a. **Is he/she a member of a men/ women's group?**	|____|
	b. **Is he/she a member of a credit, saving or**	|____|
	c. **Is he/she a member of an organised religious study**	|____|
	d. **Is he/she a member of a burial committee?**	|____|
	e. **Is he/she a member of another community**	|____| **If YES: Describe: ______________________________**
18. .	What are the ownership arrangements of the house your family lives in?	Owns(1) Pays rent/lease (2) No rent with consent of owner (3) No rent squatting (4) Code: _______Any other specify:_______________(97)
19. .	How many rooms are there in your house?	3.a. Number of rooms used for living / sleeping: ____ 3.b. Total number of rooms (bedroom, kitchen, bath): _____
20. .	Does your household own any land?	Yes (1) No (2) Don't know (98) Code:___________________
21. .	Which of the following items does your household own?	Yes (1) No (2) Don't know (98) CODE: REFRIGERATOR ____ RADIO ____ TELEVISION ____ CELL PHONE ____ BICYCLE ____ MOTOR CYCLE ____ CAR ____
22.	***INTERVIEWER TO OBSERVE AND CONFIRM***	Code: _______ Any other specify: (97)
23.	***INTERVIEWER TO OBSERVE AND CONFIRM***	Code: _______ Any other specify: (97)
24.	what are the sources of water in this community?	CodeS: _______

25.

Sources	**Source Codes**	**Usually**	**Rarely**	**Never**	**Don't Know**
		1	**2**	**3**	**98**
Piped water into apartment	**1**				
Piped water into compound	**2**				
Public standpipe	**3**				
Motorised borehole	**4**				
Handpump borehole	**5**				
Protected dug well with handpump	**6**				
Protected hand dug well	**7**				
Unprotected hand dug well	**8**				
Developed spring	**9**				
Undeveloped spring	**10**				
Rain water harvesting	**11**				
Bottled water	**12**				
Sachet (pure) water	**13**				
Tanker water vendor	**14**				
Wheelbarrow/mukokoteni vendors	**15**				
Surface water (river/pond/lake/stream/dam/canal/irrigation channels)	**16**				
Others (Specify)	**97**				

26.	What is your ***main*** drinking water source?	Code:_______________
27.	How many times do you go to the drinking water source?	No. of trips per day:____________________
28.	How long in minutes does it take to walk to the main drinking water source, collect water & return home	Minutes ________________________98 – Don't know
29.	Who usually fetches drinking water for your household?	Code: ________________________________
30.	What is your main drinking water source during **dry** season?	Code: ________________________________
31.	What is your main drinking water source during **rainy** season?	Code: ________________________________
32.	Do you use water from this drinking water source for the following activities?	Yes (1) No (2) Don't know (98)Cook ____Bath Wash cooking Utensils _____Washands_______Laundry_____________________
33.	What is your ***main*** reason for using this source?	Code: ____________ Any other (Specify) (97)

34. How satisfied are you with your main drinking water source?

	Satisfied	**Not satisfied**	**No Opinion**
Quantity			
Time it is available (flowing)			
Safety			
Taste			

35.	How far is the main drinking water source from your house?	Dry Season Metres: _______________	Rainy Season Metres:
36.	Which diseases do you think an adult can get if the drinking water is not good	CodeS: ☐ ☐ ☐ ☐ OTHERS specify_________________(97)	
37.	Which diseases do you think a child below 5 years can get if the drinking water is not good	CodeS: ☐ ☐ ☐ ☐ OTHERS specify_________________(97)	

38.	who is responsible for ensuring that your household has clean water to drink (not necessarily the fetcher)	Code:_______________________________________ Any other specify:_______________(97)		
39.	For how long has your household been using the main drinking water source	Months: ___________________________________		
40.	In the last 2 weeks has the water from your main drinking water source been unavailable for 1 or more days? **If No in 40, skip**	Yes (1) No (2) Don't know (98) Others (Specify) ________________ (97)		
41. 41	When this happened what other sources did you use for drinking	CodeS: ☐ ☐ ☐ ☐ Others (Specify)_______________(97)		
42. 43	What do you consider as the qualities of safe drinking water?	CodeS: ☐ ☐ ☐ ☐ Any other specify:_______________(97)		
43. 44	A) Which of these qualities applies to your drinking water? B) What do you do to address the problem you identified (note the action taken in terms of treatment but give an indication of type of action, e.g. treat by filtering)	Yes = 1 : No = 2)	**a) Code**	**b) Action Taken**
		Drinking waters quality		
		Not Visually clear		
		Not nice taste		
		Has an odour		
		Salty taste		
		Not free from Germs		
44. 45	Which methods of treating water have you heard about?	CodeS: ☐ ☐ ☐ ☐		
45. 46	Of the methods you have mentioned which two do you consider the best	CodeS: ☐ ☐		
46. 47	Does your household treat water before drinking?	Yes (1) No (2) Don't know (98)		
47.	Which method does your household use to treat water before drinking?	CodeS: ☐ ☐ ☐ ☐		
48.	How did you hear about your drinking water treatment method?	Code: ___________________________		
49.	If you heard through an NGO which one?	Kwaho__(1) Swap__ (2) Any other specify:____(97)		
50.	Do you have a child aged below 5 years?	Yes (1) No (2)		
51.	How many of these cups of water does the youngest child below 5 years	………………………….Cups		
52.	How many of this cups of water does the youngest child below 5 years drink in a day (Interviewer to show cup for estimation) **REPEATED**	………………………….Cups		
53.	Are there times when you have drunk untreated water in the last two weeks?	Yes (1) No (2) Don't know (98)		
54.	If yes, why did you drink untreated water?	CodeS: ☐ ☐ ☐ ☐		
SECTION C: EXCRETA DISPOSAL				
55.	What type(s) of toilet facilities do you have in your household?	CodeS: ☐ ☐ ☐ ☐ Any other specify:_______________(97)		
56.	What kind of toilet facilities do you usually use?	Code: _____________________________		
57.	The last time that an under-5 child passed stool in this house, what did she/he use?	Code: _____________________________ Any other specify:_______________(97)		
58.	How did you dispose of the child's faeces	Code: ____________________________________		

<table>
<tr><td>59.</td><td>How do you dispose of your anal cleansing materials?</td><td>Code: ____________________________________</td><td></td></tr>
<tr><td>60.</td><td>In your opinion do you think it is important for each house to have a toilet</td><td>Yes (1) No (2) Don’t know (98)
Code: ____</td><td></td></tr>
<tr><td>61.</td><td>Why do you think it is important for each household to have a toilet?</td><td>CodeS: ☐ ☐ ☐ ☐
Any other specify: (97)</td><td></td></tr>
<tr><td colspan="4">SECTION D: PERSONAL, HOUSEHOLD AND ENVIRONMENTAL HYGIENE</td></tr>
<tr><td>62.</td><td>Which diseases do you think an adult can get by not washing hands with water or with soap if they defecate?</td><td>CodeS: _______
Any other specify: ______________________(97)</td><td></td></tr>
<tr><td>63.</td><td>The last time you defecated what did you do to your hands after that?</td><td>Code: _______</td><td></td></tr>
<tr><td>64.</td><td>Where do you wash hands after defecating?</td><td>In toilet (1) in the open yard (2) in bathroom (3) In kitchen (4)
Code: ____any other</td><td></td></tr>
<tr><td>65.</td><td></td><td><table>
<tr><td></td><td></td><td>Yes (1)</td><td>No(2)</td><td>Could not</td></tr>
<tr><td>a)</td><td>Water</td><td></td><td></td><td></td></tr>
<tr><td>b)</td><td>Ash</td><td></td><td></td><td></td></tr>
<tr><td>c)</td><td>Soap</td><td></td><td></td><td></td></tr>
<tr><td>d)</td><td>Basin/Sink/Tippy</td><td></td><td></td><td></td></tr>
</table></td><td></td></tr>
<tr><td>66.</td><td>a) What do you consider to be the critical times to wash hands?
b) What agents do use to wash hands at these times?
(Multiple responses allowed)</td><td colspan="2"><table>
<tr><td>Times</td><td>Water (1)</td><td>Water &</td><td>Water & Sand</td><td>Water & Ash</td><td>Any other</td></tr>
<tr><td>Before</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Before eating</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>After eating</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Before breast-</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>After</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>After</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Before</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Before prayer</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Any Other</td><td></td><td></td><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><td>67.</td><td>In the last one day have you used soap?</td><td>Yes (1) No (2) Don’t know (98)</td><td></td></tr>
<tr><td>68.</td><td>If yes what did you use it for
Do not read the options, ask to be specific, encourage “What else” until nothing further is mentioned and</td><td>CodeS: ☐ ☐ ☐ ☐
Other (Specify):__________________________</td><td></td></tr>
<tr><td>69.</td><td>Do you share your toilet facility with other households?</td><td>Yes (1) No (2) Don’t know (98) Code:
_____________________________________</td><td></td></tr>
<tr><td colspan="4">SECTION E: WATER RELATED DISEASES</td></tr>
<tr><td>70.</td><td>What in your opinion is diarrhoea?</td><td>Code:_____________</td><td></td></tr>
<tr><td>71.</td><td>What in your opinion causes</td><td>CodeS: _______</td><td></td></tr>
<tr><td>72.</td><td>How can diarrhoea be prevented?</td><td>Code: _______</td><td></td></tr>
<tr><td>73. H</td><td>Has the youngest child had diarrhoea in the last two weeks</td><td>Yes (1) No (2) Don’t know (98)</td><td></td></tr>
</table>

SECTION F: **Observational Checklist for Respondent’s Premises (Interviewer should ask for permission to go around the premises with the respondent)***After completing the questionnaire, go round the household and observe the following.*

	Facility	**Yes =1**	**No =2**	**Type of source/ sanitation/HWTS product**	**Functional Status Functioning: =1; Non functional =2**	**Evidence of use Yes = 1;No =2**
74.	Improved water source within the premises?					
75.	Improved sanitation facility in the house					
76.	Evidence of water treatment product					
77.	Evidence of Hand washing facility					
	Other features	**Yes (1)**	**No (2)**	**Remarks**		
78.	Availability of water for hand washing					
79.	Evidence of soap in the house					
80.	Evidence of soap for hand washing (near					
81.	Evidence of ash for hand washing (near					
82.	Evidence of cover on storage container					
83.	Sanitation around the toilet facility (dry					
84.	Animal litter/excreta around the compound					
85.	Evidence of regular compound cleaning					
86.	Is there stagnant water around the water source?	Yes (1)	No(2)	No source in the yard (3)		
87.	Any other observation that may affect water quality e.g. toilet					

Appendix 3.0.2 Position of respondent in relation to the household head by study arm.

Position	Intervention		Control		Total
	Frequency	Percentage	Frequency	Percentage	
Household head	112	28.21	32	41.56	144
Spouse of HHH	259	65.24	40	51.95	299
Son/daughter in law of HHH	21	5.29	3	3.90	24
In-law of HHH	0	0.00	2	2.60	2
Father/Mother of HHH	1	0.25	0	0.00	1
Grandparent of HHH	1	0.25	0	0.00	1
Nephew/niece of HHH	1	0.25	0	0.00	1
Don't know	2	0.50	0	0.00	2
Total	397	100.00	77	100.00	474

HHH: Household head

Appendix 3.3 Educational level of KAP respondents

Education Level	Intervention		Control		Total	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
No education	55	13.85	11	14.29	66	13.92
Some primary school	108	27.20	27	35.06	135	28.48
Completed primary school	141	35.52	22	28.57	163	34.39
Some secondary not completed	62	15.62	10	12.99	72	15.19
Completed secondary	26	6.55	7	9.09	33	6.96
Some poly/university/postgraduate	3	0.76	0	0.00	3	0.63
Don't know	2	0.50	0	0.00	2	0.42
Total	397	100	77	100	474	100

Appendix 3.4 Occupation of KAP respondent by study arm.

Respondents Occupation	Intervention		Control		Total	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Not working, not looking	24	6.05	11	14.29	35	7.38
Student	10	2.52	1	1.30	11	2.32
Retired by age with pension	2	0.50	0	0.00	2	0.42
Teacher/Lecturer	6	1.51	2	2.60	8	1.69
Domestic worker for pay	7	1.76	0	0.00	7	1.48
Looking for work	8	2.02	0	0.00	8	1.69
Work on own farm only	206	51.89	31	40.26	237	50.00
Work on others farm for wage labour	3	0.76	0	0.00	3	0.63
Skilled artisan	3	0.76	1	1.30	4	0.84
Self employed Business	105	26.45	30	38.96	135	28.48
Civil servant	3	0.76	0	0.00	3	0.63
Housewife	12	3.02	0	0.00	12	2.53
Others specify	8	2.02	1	1.30	9	1.90
Total	397	100.00	77	100.00	474 (100.00)	100.00

Unemployed : Not working not looking + looking for work

Appendix 3.5 Educational level of household head.

Variable	Intervention		Control		Total	
Education level	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
No education	42	10.58	9	11.69	51	10.76
Some primary school	81	20.40	21	27.27	102	21.52
Completed primary school	120	30.23	27	35.06	147	31.01
Some secondary not completed	87	21.91	8	10.39	95	20.04
Completed secondary	57	14.36	12	15.58	69	14.56
Some poly/university/postgraduate	4	1.01	0	0.00	4	0.84
Other specify	6	1.51	0	0.00	6	1.27
Total	397	100.00	77	100.00	474	100.00

Appendix 3.6 Reasons for drinking untreated water in the previous two weeks

Variable	**Intervention n = 125**		**Control n = 25**	
Reasons for drinking untreated water in the previous two weeks	Frequency	%	Frequency	%
Forgot to treat water	5	4	1	4
Don’t like taste of treated water	5	4	0	0
I was away from home	14	11.2	4	16
Treated water finished	15	12	7	28
No time to treat water	2	1.6	0	0
Rainwater considered safe	42	33.6	7	28
No money to buy the treatment product	23	18.4	1	4
*Source is clean	13	10.4	1	4
Don’t know how to treat water	1	0.8	0	0
Don’t treat water	1	0.8	0	0
My religion does not allow	1	0.8	0	0
I was sick and could not treat	0	0	1	4
No reason	3	2.4	3	12
Total	125	100	25	100

*other sources apart from rainwater

ANNEXURE FOR CHAPTER FOUR: HOUSEHOLD WATER TREATMENT ADOPTION AND COMPLIANCE

Appendix 4.1 Adoption and compliance with household water treatment questionnaire

WATER TREATMENT ADOPTION AND COMPLIANCE QUESTIONNAIRE

Serial Number /___/___/___/___/___/___/___/ Linked to KAP Questionnaire

INTRODUCTION AND INFORMED CONSENT

READ INFORMED CONSENT FORM

Sir/Madam, My name is ____. We are conducting a survey on water and sanitation, knowledge, attitudes and practices. We would value and appreciate your participation in this exercise. The survey may take about 40 minutes. Whatever information you provide will be strictly confidential and will help you understand how to keep your drinking water safe. Participation in this survey is voluntary, and non participation attracts no penalty, though we hope that you will participate since your views are important and will help households make their water safe.

At this time do you want to ask me anything about the survey? |Yes|___| |No|___|

May I begin the interview now? |Yes|___| |No|___|

IF RESPONDENT AGREES TO BE INTERVIEWED...........................START

IF RESPONDENT DOES NOT AGREE TO BE INTERVIEWED ......END PROCESS

Date of interview: (DD/MM/YYYY) |__|__|/|__|__|/|__|__|__|__|

Interviewer ID/Name: |__|__|__| /______________________________

Signature of Interviewer: __________________________________

Time started: :

		NAME	CODE	
1.	State/Province			
2.	District			
3.	Division			
4.	Location			
5.	Sub-location			
6.	Village			
7.	Household	N/A		
8.	Respondent – responsible for ensuring clean drinking water.(Q. 38 KAP)	N/A	Gender: M|__| F|__|	

SECTION A: GENERAL INFORMATION ABOUT SOCIO DEMOGRAPHIC AND KAP OF RESPONDENT RESPONSIBLE FOR CLEAN DRINKING WATER AND HOUSEHOLD HEAD

<table>
<tr><td>1.</td><td>You have been identified as the person that makes sure the drinking water in the household is clean, is this true?</td><td>Yes=(1) No=(2)
Code:</td></tr>
<tr><td>2.</td><td>a) Are you responsible for treating water in the household?
In households that treat water interview the person</td><td>a)Yes=(1) No=(2) HH doesn't treat water=(3)
b)CodeS: ☐ ☐ ☐ ☐</td></tr>
<tr><td>3.</td><td>What is the highest level of education you have?</td><td>Code: ______________________________</td></tr>
<tr><td>4.</td><td>What do you consider as the qualities of safe drinking water?
Do not read the options. Only probe: what else?</td><td>CodeS: ☐ ☐ ☐ ☐
OTHER (Specify): _____________________(97)</td></tr>
<tr><td>5.</td><td>What is your household main drinking water source?</td><td>Code: _________________________</td></tr>
<tr><td>6.</td><td>a) Which of the qualities that you mentioned does your main drinking water source satisfy?
b) For those qualities that your water does not satisfy what actions do you take?</td><td>Yes=(1) : No=(2)
<table>
<tr><th>Drinking water</th><th>a) Code</th><th>b) Action Taken</th></tr>
<tr><td>Visually clear</td><td></td><td></td></tr>
<tr><td>Sweet taste</td><td></td><td></td></tr>
<tr><td>Odourless</td><td></td><td></td></tr>
<tr><td>Salty taste</td><td></td><td></td></tr>
<tr><td>Free from germs</td><td></td><td></td></tr>
</table></td></tr>
<tr><td>7.</td><td>Which methods of treating water have you heard about?
Multiple Responses</td><td>CodeS: ☐ ☐ ☐ ☐</td></tr>
<tr><td>8.</td><td>Does your household treat water before drinking it?
If NO continue to question 9 then skip (10-16). If YES skip 9, go</td><td>Yes=(1) No=(2) Don't know=(98)
Code: ______________________________</td></tr>
<tr><td>9.</td><td>Does your household have any specific reasons for not treating your water before you drink it? ✋
(DO NOT PROMPT. Spontaneous response. Write the codes of all that apply)</td><td>CodeS: ☐ ☐ ☐ ☐
ANY OTHER (Specify) __________(97)</td></tr>
<tr><td>10.</td><td>Does your household have any specific reasons for treating your water before you drink it? ✋
(DO NOT PROMPT. Spontaneous response. .)
Only to be filled by households that treats their water!
Multiple Responses</td><td>CodeS: ☐ ☐ ☐ ☐
OTHER (Specify) __________(97)</td></tr>
<tr><td>11.</td><td>Out of the members of your household specified in Q 6 (KAP) who consumes the treated water?
Multiple Responses</td><td>CodeS: ☐ ☐ ☐ ☐
<table>
<tr><th><i>Category</i></th><th><i>Male</i></th><th><i>Female</i></th><th><i>Total</i></th></tr>
<tr><td>Under 1</td><td></td><td></td><td></td></tr>
<tr><td>1 – <5 years</td><td></td><td></td><td></td></tr>
<tr><td>5 – 14 years</td><td></td><td></td><td></td></tr>
<tr><td>15 - 19 years</td><td></td><td></td><td></td></tr>
<tr><td>15 – 30 years</td><td></td><td></td><td></td></tr>
<tr><td>15 – 64 years</td><td></td><td></td><td></td></tr>
<tr><td>65+</td><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><td>12.</td><td>Which method(s) does your household use to treat water before drinking?</td><td>CodeS: ☐ ☐ ☐ ☐
OTHER (Specify) __________(97)</td></tr>
<tr><td>13.</td><td>Of all the treatment methods mentioned in Q.12 which method do you use most often currently</td><td>Code: ______________________________</td></tr>
<tr><td>14.</td><td>How did you learn about this method?</td><td>CodeS: ☐ ☐ ☐ ☐</td></tr>
<tr><td>15.</td><td>When was the last time you treated your water with this method</td><td>Code:</td></tr>
</table>

SECTION B: HOUSEHOLD WATER STORAGE

17.	👁	Yes=(1) Could not access=(2)
18.	How many containers are in use for water storage? Multiple Responses	

	Codes	No.	Total	Capacity/litre
CDC vessel	1			
Plastic bucket	2			
Metal bucket	3			
Clay pot	4			
Cooking pot	5			
Jerry can	6			
Plastic bottles	7			
Drum	8			
Ceramic filter	9			
Any other	97			
Don' t know	98			
Total				

19.	Which of the storage containers is your main storage container?(i.e. used most frequently)	Code: ________________________
20.	Of the containers you have mentioned which one of them did the youngest child drink from today?	Code: ________________________
21.	Is it the same as the main storage container in Q.19?	Yes=(1) No=(2) Don't
I will be asking the following questions (22 -30) about the storage container the youngest child drunk from today		
22.	What is the mouth type of the container? 👁	Code:
23.	Is storage container covered? 👁	Yes=(1) No=(2) Couldn't
24.	Where is it located? 👁	Code:
25.	Is storage container different from collection container?	Yes=(1) No=(2) Couldn't Observe=(98)
26.	Do you think it is important that the collection container is covered during transportation?	Yes=(1) No=(2) Couldn't Observe =(98)
27.	Was cover observed on collection container? 👁	Yes=(1) No=(2) Don't know=(98)
28.	How do you take drinking water from the storage container?	Code:
29.	How often do you clean this storage container?	Code:
30.	What do you usually use to clean this storage container?	Code:

SECTION C: DRINKING WATER CONSUMPTION

31.	How many cups of water do you personally drink per day?	
32.	How many cups of **treated** water do you drink per day? (If household does not treat water the answer should be zero if not probe where treated drinking water comes from)	…………………………Cups
33.	How many cups of **untreated** water do you drink per day?	…………………………Cups
34.	How many cups of **treated** water does the youngest child drink per day?	No young child in the household
35.	How many cups of **untreated** water does the youngest child drink per day?	No young child in the household

SECTION D: BEHAVIOURAL DETERMINANTS THAT INFLUENCE ADOPTION

Interviewer: I will be asking you questions which will help me know your views about the methods you said you have heard about (question 7) and above.

36.

Do you think it is good or bad to use this method to treat your water? **Refer to**

	Very good	Good	Fair	Bad	Very
Boiling					
Filtration with					
Filtration with					
Filtration with					
Addition of alum					
Liquid chlorine					
Chlorine tablet					
Chlorine +					
Settlement only					
SODIS					

question 7

37.

How effective do you think this method is for killing germs in drinking water? **Refer to question 7**

	Very	Effective	Not	Don't
Boiling				
Filtration with cloth.				
Filtration with sand				
Filtration with ceramic				
Addition of alum				
Liquid chlorine				
Chlorine tablet				
Chlorine + coagulant				
Settlement only				
SODIS				

38.

a) How much of your time do you think treating water with this method takes? {Time in minutes}

b) In your opinion is that too much or not? **Refer to question 7**

	Time	Too	Not	Interviewees
Boiling				
Filtration with cloth.				
Filtration with sand				
Filtration with ceramic				
Addition of alum				
Liquid chlorine				
Chlorine tablet				
Chlorine + coagulant				
Settlement only				
SODIS				

39.

Will you be treating your	Certainly Yes
Likely	Will use
Slightly Likely	Maybe Yes
Unlikely	Will not
Highly Unlikely	Certainly No

	V er	Li kel	Slig htly	Unlikely (4)
Boili				
Filtra				
Filtra				
Filtra				
Addi				
Liqui				
Chlo				
Chlo				
Settl				
SOD				

40.

How often does it happen that you intend to treat water and forget to do so? ***(Skip if no in question 8)***

Refer to question 7

	Frequently (1 or more times/week)	Rarely (fewer than	Never
Boiling			
Filtration with cloth.			
Filtration with sand			
Filtration with ceramic			
Addition of alum			
Liquid chlorine			
Chlorine tablet			
Chlorine + coagulant			
Settlement only			
SODIS			

41. How expensive do you think it is to treat water with the following method?

Refer to question 7

	Very	Expensive	Not	Don't
Boiling				
Filtration with				
Filtration with				
Filtration with				
Addition of				
Liquid				
Chlorine tablet				
Chlorine +				
Settlement				
SODIS				

42. Do you think the benefit outweighs the costs for your household to treat water with this method?

Refer to question 7

	Yes (1)	No (2)	Don't
Boiling			
Filtration with cloth.			
Filtration with sand			
Filtration with ceramic filter			
Addition of alum			
Liquid chlorine			
Chlorine tablet			
Chlorine + coagulant			
Settlement only			
SODIS			

43. How well do you think you can use this method?

Refer to question 7

	Very	Well (2)	fai
Boiling			
Filtration with cloth.			
Filtration with sand			
Filtration with ceramic filter			
Addition of alum			
Liquid chlorine			
Chlorine tablet			
Chlorine + coagulant			
Settlement only			
SODIS			

44.

Do any of your friends and family use this method? **Refer to question 7**

	Yes (1)	No (2)	Don't
Boiling			
Filtration with cloth.			
Filtration with sand			
Filtration with ceramic filter			
Addition of alum			
Liquid chlorine			
Chlorine tablet			
Chlorine + coagulant			
Settlement only			
SODIS			

45.

a) Which of these methods have you been taught to use?

b) Which of these were you taught by an N.G.O or Government agency? **Refer to question 7**

	Taught	Yes (1)	No (2)	Don't
Boiling				
Filtration with cloth.				
Filtration with sand				
Filtration with ceramic				
Addition of alum				
Liquid chlorine				
Chlorine tablet				
Chlorine + coagulant				
Settlement only				
SODIS				

46.	Which of these methods are you conversant with i.e. know the process? Multiple Responses	CodeS: ☐ ☐ ☐ ☐ OTHER (Specify) __________(97)
47.	Mention the materials you need to have to use this method(s) including the water treatment product itself. Interviewer to write answers	Materials for method (A) 1. ______________________________ 2. ______________________________ 3. ______________________________ Materials for method (B) 2. ________________________ 3

48.
48

How easy is it to find the materials for this method?

	Difficult(1)	Not difficult &	Easy (3)
Boiling			
Filtration with cloth.			
Filtration with sand			
Filtration with ceramic filter			
Addition of alum			
Liquid chlorine			
Chlorine tablet			
Chlorine + coagulant			
Settlement only			
SODIS – plastic bottles in sun			

49.	Do you use any of these	Yes=(1) No=(2)
50.	Which method do you use to	CodeS: ______________________________
51. 49	Did any person come to your house to tell you more about	Yes=(1) No=(2) Don't know=(98)
52. 50	How effective do you think these method(s) that we are talking about are in ***prevention*** of diarrhoea?	
53.	a) Which is the **main** water treatment method that you use? Code	

	Very effective	Effective	Fai
Boiling			
Filtration with cloth.			
Filtration with sand			
Filtration with ceramic filter			
Addition of alum			
Liquid chlorine			
Chlorine tablets			
Chlorine + coagulant			
Settlement only			
SODIS			

SECTION D: Behavioural Determinants of Compliance with Water Treatment Methods

Interview person based on the main Water Treatment In question 53

BOILING

54.	How do you know the water has boiled and can be removed from the fire? ☝**(DO NOT PROMPT Spontaneous response**	Code: ______________________________
55.	How often do you boil your household drinking water? ☝	Code: ______________________________
56.	When treating your household drinking water with boiling, mention 3 critical steps you take to ensure that your water is treated properly?	1_________2 ____________3________________
57.		
58.	When did you start treating this households' water using this method/boiling (in months)?	☐☐ Months
59.	Was it because an organisation informed you about it?	Yes=(1) No=(2) Don't know=(98)
60.	If Yes, what is the name of the organisation? Multiple Responses	1.___________________________ 2
61.	When was the last time that you treated water using this method?	Code: ______________________________
62.	Who **told** you about boiling as a method of treating water?	Code:
63.	Who **taught** you how to use boiling?	Code:
64.		
65.	When you started using this method what support did you receive from someone outside your household	Code: ______________________________
66.	Have you ever used any water treatment method apart from what you are currently using? ***Skip : if no skip 67 go to 69***	Yes=(1) No=(2) Don't know=(98) Code: _____________________________
67.	If Yes, what water treatment method were you using before the current one?	Code: _________________________ OTHER (Specify): (97)
68.	Why did you stop using the former method of water treatment?	Code: ______________________________

69.	Mention all the things **you do like** about boiling.	CodeS: ______________________________
70.	Mention all the things you **don't** like about boiling.	Code: ______________________________
71.	Are there times in the past one month that you did not boil your household drinking water? ***Skip : if no skip 72 go to 73***	Yes=(1) No=(2) Don't know=(98)
72.	If yes, Why was this?	Code: ______________________________
73.	Have any of your neighbours or friends started boiling water because you told them it is a good method?	Yes=(1) No=(2) Don't know=(98)
74.	You told me the things you don't like about boiling (read them out from question 70) Mention the two most important ones to you that if changed, will make you more satisfied with boiling	1.__________________________________ 2 __________________________________
75.	👁Do you have boiled water in your house right now in your **storage** container? a) Can you show me? b) (Does the family have 'treated' water ready to drink?)	Yes=(1) No=(2) Don't know=(98) **A** __________________________________ **B** ________________________________
76.	👁Do you have drinking water right now in your **collection** container? a) Can you show me? b) (Does the family have water in the collection container?)	Yes=(1) No=(2) Don't know=(98) **A** __________________________________ **B** ________________________________
77.	Is the source for the water in the main storage container (boiled for treatment households and unboiled for non-treatment households) the same as that taken from the	Yes=(1) No=(2) Don't know=(98) Code: ______________________________
78.	Please show me the source of the water in your **storage** container. ***Take sample from source and label source appropriately***	

CHEMICALS: - (To be filled by any chlorine based product use Pur, Aquatab, Waterguard etc.)

79.	a) What type of product do you use to treat your water? b) Can you show me? c) (Does the family have the chemical disinfectant in their house?) 👁 d) Observer to note type of chemical and name	Yes=(1) No=(2) Don't know=(98) **A** ________________________________ **B** ________________________________
80.	How often do you treat your household drinking water with this product?	Code: ______________________________
81.		
82.	When treating your household drinking water with the product, mention 3 critical steps you take to ensure that your water is treated properly?	1_________2 ____________3________________
83.	When did you start treating this households' water using this method/ (in months)?	☐ ☐ Months
84.	Was it because an organisation informed you about it?	Yes=(1) No=(2) Don't know=(98)
85.	If Yes in 84, what is the name of the organisation? Multiple Responses	1.__________________________ 2
86.	When was the last time that you treated water using this method?	Code: ______________________________
87.	Who **told** you about treating water in this way?	Code:
88.	Who **taught** you how to treat water with this product?	Code:

89.		
90.	When you started using this method what support did you receive from someone outside your household	Code: ______________________________
91.	Have you ever used any water treatment method apart from what you are currently using? ***Skip : if no skip 92 go to 94***	Yes=(1) No=(2) Don't know=(98) Code: _____________________________
92.	If Yes, what water treatment method were you using before the current one?	Code: _________________________ OTHER (Specify) __________________ (97)
93.	Why did you stop using the former method of water treatment?	Code: ______________________________
94.	Mention all the things **you do like** about using this product.	CodeS: ______________________________
95.	Mention all the things you **don't** like about using this product to treat water.	Code: ______________________________
96.	Are there times in the past one month that you did not treat your household drinking water with this method? ***Skip : if no skip 97 go to 98***	Yes=(1) No=(2) Don't know=(98) Code: ______________________________
97.	If yes, Why was this?	Code: ______________________________
98.	Have any of your neighbours or friends started using this same type of product to treat water because you told them it	Yes=(1) No=(2) Don't know=(98)
99.	You told me the things you don't like about using this product (read them out from question 70) Mention the two most important ones to you that if changed, will make you more satisfied with using this product	1.__________________________________ 2 __________________________________
100.	👁Do you have treated water in your house right now in your **storage** container? c) Can you show me? d) (Does the family have 'treated' water ready to drink?)	Yes=(1) No=(2) Don't know=(98) **A** __________________________________ **B** ________________________________
101.	👁Do you have treated drinking water right now in your **collection** container? c) Can you show me? d) (Does the family have water in the collection container?)	Yes=(1) No=(2) Don't know=(98) **A** __________________________________ **B** ________________________________
102.	Did you take the treated water in your storage container from the same source as the water in the collection container?	Yes=(1) No=(2) Don't know=(98)
103.	Please show me the source of the water in your **storage** container. ***Take sample from source and label source appropriately***	

SODIS (*NOTE: -* this is not just putting out in the sun but putting in plastic bottles in sun)

104.	a) Do you use SODIS to treat your water? c) Can you show me the container you use to treat? d) (Does the family have the bottles in their house?) 👁 e) Observer to note type of container and colour	Yes=(1) No=(2) Don't know=(98) **A** ________________________________ **B** ________________________________
105.	How often do you treat your household drinking water with this product?	Code: ______________________________
106.		

107.	When treating your household drinking water with the SODIS, mention 3 critical steps you take to ensure that your water is treated properly?	1_________2 ____________3________________
108.	When did you start treating this households' water using this method/ (in months)?	☐ ☐ Months
109.	Was it because an organisation informed you about it?	Yes=(1) No=(2) Don't know=(98)
110.	If Yes in 109, what is the name of the organisation? Multiple Responses	1.__________________________ 2
111.	When was the last time that you treated water using this method?	Code: ______________________________
112.	Who **told** you about treating water in this way?	Code:
113.	Who **taught** you how to treat water with sunlight?	Code:
114.		
115.	When you started using this method what support did you receive from someone outside your household	Code: ______________________________
116.	Have you ever used any water treatment method apart from what you are currently using? ***Skip : if no skip 117 go to 119***	Yes=(1) No=(2) Don't know=(98) Code: _____________________________
117.	If Yes, what water treatment method were you using before the current one?	Code: _________________________
118.	Why did you stop using the former method of water treatment?	Code: ______________________________
119.	Mention all the things **you do like** about using sunlight to treat water.	CodeS: ______________________________
120.	Mention all the things you **don't** like about using sunlight to treat water.	Code: ______________________________
121.	Are there times in the past one month that you did not treat your household drinking water with this method? ***Skip : if no skip 122 go to 123***	Yes=(1) No=(2) Don't know=(98) Code: ______________________________
122.	If yes, Why was this?	Code: ______________________________
123.	Have any of your neighbours or friends started using this same type of product to treat water because you told them it	Yes=(1) No=(2) Don't know=(98)
124.	You told me the things you don't like about using this product (read them out from question 119) Mention the two most important ones to you that if changed, will make you more satisfied with using this product	1.__________________________________ 2 __________________________________
125.	👁Do you have treated water in your house right now in your **storage** container? e) Can you show me? f) (Does the family have 'treated' water ready to drink?)	Yes=(1) No=(2) Don't know=(98) **A** __________________________________ **B** ________________________________
126.	👁Do you have treated drinking water right now in your **collection** container? e) Can you show me? f) (Does the family have water in the collection container?)	Yes=(1) No=(2) Don't know=(98) **A** __________________________________ **B** ________________________________
127.	Did you take the treated water in your storage container from the same source as the water in the collection container?	Yes=(1) No=(2) Don't know=(98)

128.	Please show me the source of the water in your **storage** container. ***Take sample from source and label source appropriately***	

CERAMIC FILTRATION

129.	a) Do you use ceramic filter to treat your water? f) Can you show me the filter you use to treat? g) (Does the family have the filter in their house?) 👁 h) Observer to note type of filter	Yes=(1) No=(2) Don't know=(98) **A** ______________________________ **B** ______________________________
130.	How often do you treat your household drinking water with this product?	Code: ____________________________
131.		
132.	When treating your household drinking water with the filter, mention 3 critical steps you take to ensure that your water is treated properly?	1_________2 ___________3_______________
133.	When did you start treating this households' water using this method/ (in months)?	☐☐ Months
134.	Was it because an organisation informed you about it?	Yes=(1) No=(2) Don't know=(98)
135.	If Yes in 134, what is the name of the organisation? Multiple Responses	1.___________________________ 2.___________________________
136.	When was the last time that you treated water using this method?	Code: ____________________________
137.	Who **told** you about treating water with ceramic filter?	Code:
138.	Who **taught** you how to treat water with ceramic filter?	Code:
139.		
140.	When you started using this method what support did you receive from someone outside your household	Code: ____________________________
141.	Have you ever used any water treatment method apart from what you are currently using? ***Skip : if no skip 141 go to 144***	Yes=(1) No=(2) Don't know=(98) Code: ____________________________
142.	If Yes, what water treatment method were you using before the current one?	Code: ________________________ OTHER (Specify): __________________ (97)
143.	Why did you stop using the former method of water treatment?	Code: ____________________________
144.	Mention all the things **you do like** about using ceramic filter to treat water.	CodeS: ____________________________
145.	Mention all the things you **don't** like about using ceramic filter to treat water.	Code: ____________________________
146.	Are there times in the past one month that you did not treat your drinking water with ceramic filter? ***Skip : if no skip 146 go to 148***	Yes=(1) No=(2) Don't know=(98) Code: ____________________________
147.	If yes, Why was this?	Code: ____________________________
148.	Have any of your neighbours or friends started using this same type of product to treat water because you told them it	Yes=(1) No=(2) Don't know=(98)
149.	You told me the things you don't like about using this product (read them out from question 144) Mention the two most important ones to you that if changed, will make you more satisfied with using this product	1.________________________________ 2 ________________________________

150.	👁Do you have treated water in your house right now in your **storage** container? g) Can you show me? h) (Does the family have 'treated' water ready to drink?)	Yes=(1) No=(2) Don't know=(98) **A** ________________________________ **B** ______________________________
151.	👁Do you have treated drinking water right now in your **collection** container? g) Can you show me? h) (Does the family have water in the collection container?)	Yes=(1) No=(2) Don't know=(98) **A** ________________________________ **B** ______________________________
152.	Did you take the treated water in your storage container from the same source as the water in the collection container?	Yes=(1) No=(2) Don't know=(98)
153.	Please show me the source of the water in your **storage** container. ***Take sample from source and label source appropriately***	

Appendix 4.2 Qualities of safe drinking water.

Variable	Intervention		Control	
Qualities of safe drinking water, n = 474	Frequency	%	Frequency	%
Visually clear	338	85.14	72	93.51
Free from germs	313	78.84	61	79.22
Sweet taste	15	3.78	2	2.60
Odorless	54	13.60	13	16.88
Salty taste	2	0.50	0	0
No taste	23	5.79	5	6.49
Colorless	6	1.51	2	2.60
Any other	1	0.25	0	0
Total* Multiple responses	*752	1*88.91	*155	*201.3

Appendix 4.3 Water treatment methods that the respondents have heard about and use most currently.

		Heard About			**Current Main Method = 473**			
Variable	**Intervention n = 397**		**Control = 397**		**Intervention n= 396**		**Control n= 77**	
Treatment Methods n	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Waterguard	366	92.19	72	93.51	277	69.95	53	68.83
Aquatab	202	50.88	28	36.36	53	13.38	3	3.9
Boiling	206	51.89	43	55.84	22	5.56	6	7.79
Filtration with ceramic	22	5.54	0	0	20	5.05	0	0
PUR	173	43.58	23	29.87	15	3.89	2	2.58
Addition of alum	38	9.57	3	3.9	0	0	0	0
Filtration with cloth	18	4.53	7	9.09	1	0.25	1	1.3
Settlement only	3	0.76	0	0	0	0	0	0
SODIS	3	0.76	1	1.3	0	0	0	0
Filtration with candle	1	0.25	1	1.3	0	0	0	0
Filtration with sand	1	0.25	0	0	0	0	0	0
Don't know	5	1.26	0		2	0.51	0	0
Don't treat water					6	1.52	12	15.58
Total*	***1038**	***261.46**	***178**	***231.17**	**396**	**100**	**77**	**100**

*Multiple responses and % will not add up to100%

Appendix 4.4 Respondents' reasons for treating household drinking water.

Variable	**Intervention n = 397**		**Control = 77**	
Reason **n = 474**	Frequency	%	Frequency	%
Unclean water can make me sick	350	88.16	54	70.13
Source is unclean	69	17.38	12	15.58
Water looks dirty	47	11.84	5	6.49
To improve the taste	15	3.78	0	0
I was given the treatment	6	1.51	3	3.90
People told us to treat	5	1.26	2	2.60
Water has bad smell	3	0.76	1	1.30
To kill germs	49	12.34	18	81.82
I Like treated water	1	1.37	1	4.55
Shared by many	1	1.37	0	0
Religious belief	1	1.37	0	0
To eliminate dirt	1	1.37	0	0
Total* Multiple Responses	548	142.51	96	186.37

Appendix 4.5 Safe storage characteristics of main storage container

Variable	**Intervention n = 397**		**Control n = 77**	
Mouth type of the	Freq	%	Freq	%
Wide(hand can fit)	332	83.63	73	94.81
Narrow(hand can't fit)	41	10.33	3	3.90
Has a tap	24	6.05	1	1.30
Total	397	100	77	100

	Intervention = 397						**Control = 77**					
Observation of Cover n = 474	Yes		No		Couldn't		Yes		No		Couldn't	
	Freq	%	Freq	%	Freq	%	Freq	%	Fr	%	Freq	%
	385	96.98	11	2.77	1	0.25	76	98.70	1	1.30	0	0

	Intervention		**Control**	
Location of Storage	Freq	%	Freq	%
Elevated, below 1 m	256	64.48	61	79.22
On floor	132	33.25	15	19.48
Elevated, above 1 m	8	2.02	1	1.30
Don't know	1	0.25	0	0
Total	**397**	**100**	**77**	**100**

n : sample size; freq : frequency

Appendix 4.6 Method of taking water from main drinking water storage container and frequency of cleaning.

Method n = 474	**Intervention**		**Control**	
	Frequency	%	Frequency	%
Dipping with cup/calabash	352	88.66	73	94.81
Pouring	27	6.80	3	3.90
Spigot or tap	16	4.03	1	1.30
Both pouring an dipping	2	0.50	0	0
Total	**397**	**100**	**77**	**100**
Frequency of Cleaning Storage Container n	Frequency	%	Frequency	%
At least once every week	352	88.89	73	94.81
At least once every two weeks	28	7.07	3	3.90
At least once per day	10	2.53	0	0
Rarely (> 1 month)	4	1.01	0	0
At least once every month	2	0.51	1	1.30
Total	**396**	**100**	**77**	**100**
Cleaning Material n = 471 * 3 missing	Frequency	%	Frequency	%
Water only	324	82.23	74	96.10
Soap/detergent	64	16.24	3	3.90
Mud/sand	1	0.25	0	0
Ash	1	0.25	0	0
Any other	3	0.76	0	0
Don't know	1	0.25	0	0
Total	**394**	**100**	**77**	**100**

Appendix 4.7 Collection container-related knowledge attitudes and practices.

Variable	**Intervention = 395**						**Control = 77**					
storage container differs from collection container? n = 472	Yes		No		Couldn't		Yes		No		Couldn't	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
	387	97.97	7	1.77	1	0.25	76	98.70	1	1.30	0	0
	Intervention = 397						**Control = 77**					
Considers it important that the collection container is covered during transportation? n	Yes		No		Couldn't		Yes		No		Couldn't	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
	370	93.20	23	5.79	4	1.01	74	96.10	2	2.60	1	1
	Intervention = 397						**Control = 77**					
Observation of cover on the collection container? n = 474	Yes		No		Don't know		Yes		No		Don't	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
	268	67.51	129	32.4	0	0	56	72.73	21	27.27	0	0

Appendix 4.8 Daily drinking water consumption of respondent**.**

Number of Cups (Total in ml)	**Number of cups of treated water drunk per day n = 470**				**Number of cups of untreated water drunk per day n = 410**			
	Intervention		**Control**		**Intervention**		**Control**	
	Freq	**%**	**Freq**	**%**	**Freq**	**%**	**Freq**	**%**
0 (0)	10	2.54	3	3.90	311	89.11	52	85.25
1-4 (250 – 1000ml)	213	54.21	31	40.26	35	10.03	8	13.12
5-8 (1250 – 2000ml)	162	41.22	41	53.25	3	0.86	1	1.64
9-12 (2250 – 3000)	8	2.03	2	2.60	0	0	0	0
Total	393	100	77	100	349	100	61	100

Cup capacity = 250 ml

Appendix 4.9 Chlorine residual levels in respondent's drinking water storage containers.

	Inadequate n 33 (0.1 - <0.2 mg/l)				Adequate n = 92 (0.2 – 2 mg/l)				Excessive n = 3 (>5 mg/l)			
	Intervention n =33		Control n = 7		Intervention n = 92		Control n = 24		Intervention n = 2		Control n = 0	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
Waterguard IG	29	27.36	5	21.74	75	70.75	18	78.26	2	1.89	0	0
Aquatab n 18	3	16.67	0	0	15	83.3	2	100	0	0	0	0
PUR n = 3 CG	1	33.33			2	66.67	2	100	0	0	0	0

Appendix 4.10 Qualities respondents like about their current water treatment methods.

	Intervention										Control									
	Boiling		WG		Aquatab		PUR		Ceramic Filters		Boiling		WG		Aquatab		PUR		Ceramic filters	
	n	%	N	%	N	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Efficacy	17	53.13	207	36.83	43	33.33	14	58.33		0	4	44.44	44	35.2	2	33.33	1	25	N/A	N/A
Quantity	4	12.50	32	5.69	9	6.98	1	4.17	9	19.15	1	11.11	6	4.8	0	0.00	1	25	N/A	N/A
Effect on clarity	3	9.38	16	2.85	6	4.65	1	4.17	5	10.64	1	11.11	2	1.6	0	0.00	1	25	N/A	N/A
Ease of accessing	3	9.38	85	15.12	18	13.95	1	4.17		0.00	2	22.22	12	9.6	1	16.67	0	0	N/A	N/A
Affordable	2	6.25	105	18.68	28	21.71	5	20.83	5	10.64	0	0.00	24	19.2	1	16.67	1	25	N/A	N/A
No special equipment required	1	3.13	5	0.89	0	0.00	0	0.00	4	8.51	0	0.00	1	0.8	0	0.00	0	0	N/A	N/A
No harmful addition to water	1	3.13	3	0.53	1	0.78	0	0.00		0.00	1	11.11	0	0	0	0.00	0	0	N/A	N/A
Quick		0.00	76	13.52	18	13.95	2	8.33	3	6.38		0.00	32	25.6	1	16.67	0	0	N/A	N/A
Ability to use		0.00	13	2.31	1	0.78	0	0.00	10	21.28		0.00	3	2.4	1	16.67	0	0	N/A	N/A
Taste		0.00	20	3.56	5	3.88	0	0.00	11	23.40		0.00	1	0.8	0	0.00	0	0	N/A	N/A
Any other	1	3.13		0		0.00		0.00		0.00	0	0.00		0		0.00		0	N/A	N/A
Total	32	100	562	100	129	100	24	100	47	100	9	100	125	100	6	100	4	100	N/A	N/A

ANNEXURE FOR CHAPTER FIVE: DETERMINATION OF WATER QUALITY CHANGES

Appendix 5.1: Tracking tool: determination of water quality questionnaire

Date of observation: (DD/MM/YYYY)|__|__|/|__|__|/|__|__|__|__|

Interviewer ID/Name: |__|__|__| /______________________________

Signature of observer: __________________________________

Serial Number: /___/___/___/___/___/___/___/___/

TRACKING ? Yes|__| No|__|

HWTS EFFECTIVENESS ? Yes|__| No|__|

USER ACCEPTABILITY ? Yes|__| No|__|

HEAVY METAL Yes|__| No|__|

<u>SECTION A: GPS</u>

3. GPS location of compound: S |__|__| ′ |__|__| . |__|__|__| E|__|__|__| ′ |__|__| . |__|__|__|
4. (a) Elevation |_______|m (b) Accuracy |_______|m
   (c) GPS Waypoint # |_______| (d) GPSID |__| |__|__|

Time started: :

		NAME	CODE	
1.	State/Province			
2.	District			
3.	Division			
4.	Location			
5.	Sub-location			
6.	Village			
7.	Household	N/A		
8.	Respondent – responsible for ensuring clean drinking water.	N/A	Gender: M F	

	👁(Q 17) May I please see the containers you use to store your drinking water?	Yes=(1) Could not access=(2)	Yes=(1) Could not access=(2) Code:
	(Q 19) Which of the storage containers is your main storage container?(i.e. used most frequently)	Code:	Code: _______________________________
	(Q 20) Of the containers you have mentioned which one of them did the youngest child drink from today? PUT	Code: ___	Code: _______________________________
	(Q 21) Is it the same as the main storage container in Q.19?	Yes=(1) No=(2) Don't know=(98)	Yes=(1) No=(2) Don't know=(98)
I will be asking the following questions (22 -30) about the storage container the youngest child drunk from today			
	(Q 22) What is the mouth type of the container? 👁	Code: __________	Code: _________________________
	(Q 23) Is storage container covered? 👁	Yes=(1) No=(2) Couldn't	Yes=(1) No=(2) Couldn't observe=(98)
	(Q 24) Where is it located? 👁	Code: ___________	Code:
	(Q 25)Is storage container different from collection container?	Yes=(1) No=(2) Couldn't	Yes=(1) No=(2) Couldn't Observe=(98)
	(Q 26) Do you think it is important that the collection container is covered during transportation?	Yes=(1) No=(2) Couldn't Observe	Yes=(1) No=(2) Couldn't Observe =(98)
	(Q27)Was cover observed on collection container? 👁	Yes=(1) No=(2) Don't know=(98)	Yes=(1) No=(2) Don't know=(98)
	(Q 28) How do you take drinking water from the storage container?	Code: _____	
	(Q 30) How often do you clean this storage container?	Code: _________	
	What do you usually use to clean this storage container?	Code: __________	
	Which of the storage containers is your main storage container?(i.e. used most frequently)	Code: __________	Code: _______________________________
	Of the containers you have mentioned which one of them did the youngest child drink from today?	Code: __________	Code: _______________________________
	Is it the same as the main storage container in Q.19?	Yes=(1) No=(2) Don't know=(98) Code: _____	Yes=(1) No=(2) Don't know=(98) Code: _______________________________
	(Q 5) What is your household main drinking water source?		CODE___________________________
	(Q 53) Which is the **main** water treatment method that you use?		Code ________________

	(Q 61, 86,112, 138, 164) When was the last time that you treated water using this method?	Code: ___________________	Code: ______________________________
	Q (79, 105, 131,157) e) What type of product do you use to treat your water? f) Can you show me? g) (Does the family have the pot/ chemical disinfectant /bottles/ filter in their house?) 👁 h) Observer to note type of pot/ chemical ,specific type of filter, bottles name	Yes=(1) No=(2) Don't know=(98) A ___________________ ______________ B ___________________ _____________ C ___________________ _______________ D Name of chemical/bottle/filter as written ___________	Yes=(1) No=(2) Don't know=(98) A _________________________________ B ________________________________ C __________________________________ D Name of chemical/bottle/filter as written ___________ ____________________
	(Q 55, 80, 106, 132, 158,) How often do you treat your household drinking water with this product? ✋	CODE____________ _________________	CODE_____________________________
	👁(Q 75,101,127,153,179) i) Do you have 'treated' water in your house right now in your **storage** container?	Yes=(1) No=(2) Don't know=(98) **A**	Yes=(1) No=(2) Don't know=(98) **A** _________________
	👁(76,102,128,154180) i) Do you have drinking water right now in your **collection** container? j) Can you show me? k) (Does the family have water in the collection container?) Ask family to give you water for analysis from the collection container which the youngest child in the house uses (Treated water or untreated water)	Yes=(1) No=(2) Don't know=(98) **A** ___________________ **B** ___________________ **C**____________	Yes=(1) No=(2) Don't know=(98) **A** __________________________________ **B** ________________________________ **C** ________________________________
	(Q77, 103, 129, 155, 181)Is the source for the water in the main storage the same as that taken from the **collection** container?	Yes=(1) No=(2) Don't know=(98)	Yes=(1) No=(2) Don't know=(98)
	(Q 78, 104, 130, 156, 182) Please show me the source of the water in your **storage** container. ***Take sample from source and label source appropriately***		

Appendix 5.2 Arithmetic and geometric means of total coliform concentrations in water samples tracked from source to point-of-use.

Source Type	Number of households from which samples were taken in triplicate and types of sources used	Arithmetic mean ±SD at source	Arithmetic mean ±SD at collection	Arithmetic mean ±SD at storage	Geometric mean ±SD at source	Geometric mean ±SD at collection	Geometric mean ±SD at storage
Improved Sources	**71**	1528.58±2181.93	1317.32±1419.62	814.73±677.53	936.26±987.88	688.51±676.44	328.17±364.94
Public Stand pipe	11	37.2±50.41	521.82±1255.96	665.46±1870.65	6.05±10.28	67.35±12.27	78.07±9.94
Motorised Borehole	10	814±473.39	336±228.14	372±236.12	714.55±1.67	280.68±1.84	303.94±2.00
Hand Pump Borehole	3	720	353.33±317.70	50±60.83	720±1	274.73±2.31	28.84±3.61
PDW with HP	7	678.86±315.02	1744.29±836.52	1255.71±843.86	618.89±1.59	1591.68±1.58	943.21±2.55
Rain	40	5392.86±5709.16	3631.16±5989.82	1730.5±3968.92	2621.98±5.27	1228.11±6.63	286.80±10.87
Unimproved Sources	**46**	8008±7978.07	6520±7202.89	3351±4177.48	5672.42±4748.69	3858±3713.59	1039±945.12
UPHDW	3	2366.67±635.09	1426.67±952.96	396.67±185.83	2314.59±1.29	1232.01±1.93	370.98±1.55
Surface water	43	13649.36±10207.23	11613.10±9844.95	6304.52±8222.25	9030.25±2.87	6483.82±3.85	1707.58±9.38
Total	117						

Improved sources: public standpipe, motorised borehole, handpump borehole, PDW with HP (protected dug well with handpump), rain; unimproved sources: UPHDW (unprotected handdug well), surface water, mean±SD: mean concentration ± standard deviation.

Appendix 5.3 Arithmetic and geometric means of *Escherichia coli* concentrations in water samples tracked from source to point of use.

Source Type	Number of households from which samples were taken in triplicate and types of sources used	Arithmetic mean ±SD at source	Arithmetic mean ±SD at collection	Arithmetic mean ±SD at storage	Geometric mean ±SD at source	Geometric mean ±SD at collection	Geometric mean ±SD at storage
Improved Sources	71	59.06±113.72	89.01±136.50	9.79±11.50	5.71±8.69	6.34±6.81	3.64±4.04
Public Stand pipe	11	0	10±19.49	10.91±30.15	0	2.60±5.22	2.00±4.85
Motorised Borehole	10	0	3±6.75	1±3.16	0	1.70±3.09	1.26±2.07
Hand Pump Borehole	3	0	0	0.00	0	0	0
PDW with HP	7	34.57±38.71	114.29±251.45	28.57±39.76	19.64±3.16	12.95±10.35	10.14±6.04
Rain	40	260.71±539.29	317.75±734.51	8.475±201.70	8.91±22.35	14.47±20.72	4.78±11.32
Unimproved Sources	46	1441.94±1643.22	923.94±1202.94	227.56±251.11	296.67±129.35	145.70±178.74	18.95±10.97
UPHDW	3	280±277.13	73.33±94.52	50±78.10	205.20±2.53	19.31±14.47	11.19±11.85
Surface water	43	2603.87±2572.42	1774.55±2511.28	405.12±1233.26	388.13±30.45	272.08±17.60	26.71±16.87
Total	**117**						

Appendix 5.4 Self-reported household water treatment method versus observed water treatment method

	Self Reported Water Treatment Method				**Observed Water Treatment Method**			
Main water treatment method n = 116 (missing frequency = 1)	**Intervention n = 86**		**Controls n =30**		**Intervention n = 76**		**Controls n =15**	
	Frequency	**%**	**Frequency**	**%**	**Frequency**	**%**	**Frequency**	**%**
Liquid Chlorine n = 60 (51.72%)	41	47.67	19	63.33	37	90.24	13	68.42
Chlorine Tablet n = 12 (10.34%)	10	11.63	2	6.67	10	83.33	2	100.00
Boiling n = 7 (6.03%)	5	5.81	2	6.67	1	20.00	1	50.00
Filtration with ceramic filter n = 20 (17.24%)	20	23.26	0	0	20	100.00	0	0.00
Chlorine Coagulant n =8 (6.90%)	8	9.3	0	0	8	100.00	0	0.00
Filtration with cloth n = 0	0	0	0	0	0			
Don’t treat water 9 (7.76%)	2	2.32	7	23.33				
Total	86	100	30	100	76	*393.58	16	*218.42

Denominator of observed treatment method is number of self-reported method, n = sample size

ANNEXURE FOR CHAPTER SIX: ASSESSING THE EFFECTIVENESS OF HOUSEHOLD WATER TREATMENT TECHNOLOGIES

Appendix 6.1 Number of water samples collected from households in 1st, 2nd and 3rd assessments of the household water treatment technologies.

Village	**HWT technology assessed**	**Source category**	**Water source type**	**Number of sources**	**Number of sampled households using these sources**
Tito	Ceramic filters	Unimproved	Surface water - stream	2	2
			Surface water - pond		1
		Improved	Rainwater		7
Total					**10**
Angeyoni	Aquatab	Improved	Borehole with handpump	1	1
			Rainwater		2
Akado	Aquatab	Unimproved	Unprotected handdug well	1	3
		Improved	Public standpipe	1	1
			Rain water		2
Total					**9**
Kokul	Waterguard	Unimproved	Surface water	1	9
		Improved	Rainwater	1	1
Total					**10**
Kinasia	PUR	Unimproved	Surface water	3	7
		Improved	Rainwater	1	1
					8
Grand total				***11**	**37**

Rainwater sampled from containers not shown in table

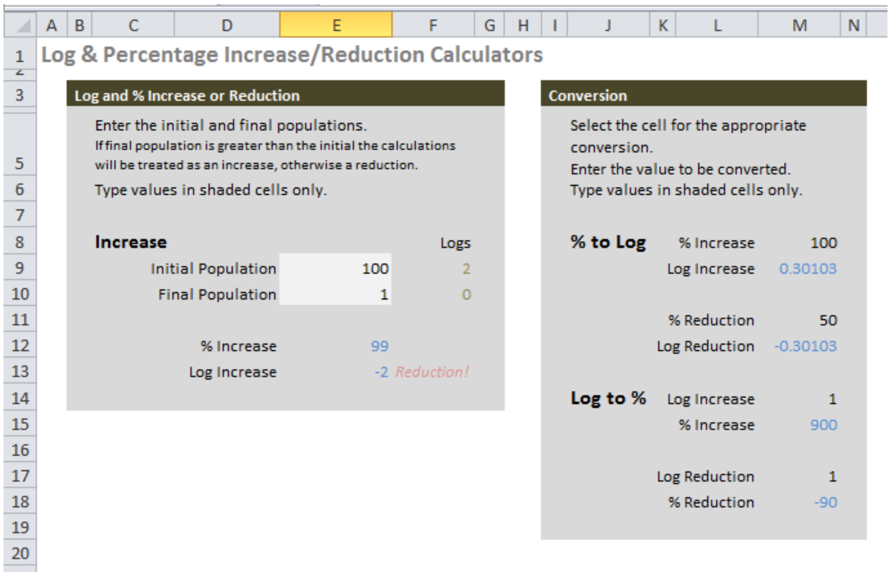
Appendix 6.2 Calculator for Log/Percentage Increase/Reduction created in MS Excel®.

The following equations are used in the spreadsheet calculations:

$$\%\ \text{Increase (or Reduction)} = \frac{(\text{Final Population} - \text{Initial Population})}{\text{Initial Population}}$$

$$\text{Log Increase (or Reduction)} = \log_{10}(\text{Final Population}) - \log_{10}(\text{Initial Population})$$

Figure A1: Excel® Spreadsheet Calculator Interface



Log & Percentage Increase/Reduction Calculators

Log and % Increase or Reduction

Enter the initial and final populations.
If final population is greater than the initial the calculations will be treated as an increase, otherwise a reduction.
Type values in shaded cells only.

Increase Logs
Initial Population 100 2
Final Population 1 0

% Increase 99
Log Increase -2 *Reduction!*

Conversion

Select the cell for the appropriate conversion.
Enter the value to be converted.
Type values in shaded cells only.

% to Log % Increase 100
Log Increase 0.30103

% Reduction 50
Log Reduction -0.30103

Log to % Log Increase 1
% Increase 900

Log Reduction 1
% Reduction -90

Table A1: Cell Formulas Used in the MS Excel® Spreadsheet

Cell Address	Formula
C8	=IF(C5>C4,"Increase","Reduction")
F9	=IF(E9<=0,"undefined",LOG10(E9))
F10	=IF(E10<=0,"undefined",LOG10(E10))
F11	=IF(E10>0,F10,LOG10(1))-IF(E9>0,F9,LOG10(1))
E12	=(E9-E10)/E9*100
E13	=IF(AND(E9>0,E10>0),F11,"> "&ABS(ROUND(F11,3)))
M9	=LOG10(1+ABS(M8)*0.01)
M12	=LOG10(1-ABS(M11)*0.01)
M15	=(10^ABS(M14)-1)*100
M18	=(1-10^ABS(M17))/10^ABS(M17)*100

Appendix 6.3 Summary of performance requirements for small-scale and household drinking water treatment based on reference pathogens *Campylobacter jejuni*, *Crystosporidium* and rotavirus (WHO, 2011).

Target	Log $_{10}$ reduction required	Log $_{10}$ reduction required	Log $_{10}$ reduction required
Highly	=4	=5	=4
Protective	=2	=3	=2
Interim	Achieves protective target for two classes of pathogens and results in health gains		

Appendix 6.4 Physico-chemical properties of samples taken from sources during the 1st, 2nd and 3rd HWTS assessments, MAL refers to the maximum allowable limits of the parameters in drinking water according to WHO (2008) drinking water guidelines.

Source Type	pH MAL: 6.5-8.5				EC us/cm				Temp				Turbidity (NTU) MAL :NTU			
	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max	Mean	Std Dev
Public standpipe (4)	6.53	7.06	6.67	0.23	126	206	146	34.64	24.23	25.3	24.5	0.46	4.5	5	4.63	0.25
Handpump borehole (9)	7.4	7.43	7.41	0.01	966	983	971.67	8.01	25.8		25.97	0.24	4.5	5	4.67	0.24
protected handdug well (7)	6.87	7.43	6.99	0.2	16	1376	1152.38	465.1	23.1	26.6	25.18	1.15	4.5	7	5.31	0.99
Rainwater (36)	6.31	9.23	7.59	0.72	8	205	31.67	39.36	19	27.43	22.3	2.85	4.5	200	10.28	32.54
Surfacewater (77)	6.87	9.58	8.29	0.51	24	840	376.87	99.61	21	31.17	24.51	2.12			210.3	189.3

The values that were < 5 NTU the detection limit of the turbidity tube were assigned values of 4.5 NTU for calculation purposes

Appendix 6.5 Arithmetic and geometric mean concentrations of *Escherichia coli* and total coliforms in water samples during 1st HWT assessment.

Technology	Source category		Source				Collection				Storage			
		No of households that samples were taken from in triplicates	AM Mean EC/100ml ±SD at source	AM Mean TC/100ml ±SD at source	GM Mean EC/100ml ±SD at source	GM Mean TC/100ml ±SD at source	AM Mean EC/100ml ±SD at collection	AM Mean TC/100ml ±SD at collection	GM Mean EC/100ml ±SD at collection	GM Mean TC/100ml ±SD at collection	AM Mean EC/100ml ±SD at storage	AM Mean TC/100ml ±SD at storage	GM Mean EC/100ml ±SD at storage	GM Mean TC/100ml ±SD at storage
Aquatab	**Unimproved**	**3**	**280±277.13**	**2366.67±635.09**	**205.20±2.53**	**2314.59±1.29**	73.33±94.52	1426.67±952.96	19.31±14.47	1232.01±1.93	50±78.10	396.67±185.83	11.187±11.87	370.98±1.55
	Improved	**6**	**0**	**863.33±873.86**	**1±1**	**449.33±5.33**	63.33±155.13	815±1007.13	2.69±11.30	70.49±36.55	0	163.33±339.10	0	11.10±18.02
	Combined	**9**	**140±232.90**	**1615±1069.95**	**14.33±19.58**	**1019.82±4.05**	66.67±131.53	1018.89±976.99	5.19±12.63	182.93±24.56	16.67±46.38	241.11±306.78	2.24±5.63	35.75±17.99
PUR	**Unimproved**	7	398.33±750.37	4886.67±5490.62	9.95±35.98	3258.56±2.52	602.86±687.33	6492.86±6398.40	95.26±25.11	3735.41±3.77	298.57±397.51	2762.86±1863.37	100.37±9.31	2362.56±1.78
	Improved	1	0	4,600	0	4600.366	1,510	4290	3.18	3.63	10	700	0	2.85
	Combined	8	341.43±701.35	4845.71±5013.40	7.17±29.49	3423.07±2.35	716.25±712.60	6217.5±5974.74	134.57±23.11	3800.61±3.42	262.5±381.90	2505±1872.98	95.23±9.22	2029.30±1.99
Waterguard	**Unimproved**	9	4200±0	30150±2100	4200±1	31200±1.08	1458.89±1680.61	16892.22±12960.90	362.69±14.77	7861.01±6.38	192.22±192.73	12768.89±12289.89	56.38±11.35	4940.92±7.02
	Improved	1	N/D	N/D	N/D	N/D	1000	28000	3	4.45	300	1030	2.45	3.01
	Combined	10	4200±0	30150±2100	4200±1	31200±1.08	1413±1591.13	8003±12714.49	401.40±12.92	8925.78±6.00	203±184.88	1595±12167.13	66.64±10.50	4223.87±6.71
Ceramic filters	**Unimproved**	3	2400±4156.92	4090±4156.92	19.31±168.67	2939.17±2.61	316.67±4128.05	06.67±4128.05	373.66±17.63	5161.60±2.56	4200±4156.92	5290±5091.17	19.31±168.67	3876.09±3.23
	Improved	7					132.86±216.77	567.14±618.92	12.21±15.51	1381.44±1.90	1.43±3.78	611.43±677.01	1.39±2.38	277.35±5.48
	Combined	10	2400±4156.92	4090±4156.92	19.31±168.67	2939.17±2.61	1538±2989.49	3049±3120.14	50.36±32.15	2051.49±2.55	721±2400	651.11±2946.09	3.06±19.31	498.37±7.76

AM mean EC/100 ml: Arithmetic mean *Escherichia coli*/100 ml ±standard deviation; GM TC/100 ml: Geometric mean total coliform ± standard deviation

Appendix 6.6 Arithmetic means, percentage and log reductions of *E. coli* in drinking water samples from collection and storage containers (before and after treatment) with HWTS technologies (1st assessment).

Technology	Water source category	No. of sampled household collection and storage containers	A.Mean *E. coli* /100ml ±SD at collection	A.Mean *E. coli* /100ml ±SD at storage	% reduction	Log reduction value
Aquatab	Unimproved	3	73.33±94.52	50±78.10	31.82	0.17
	Improved	6	63.33±155.13	0	100.00	>1.80
	Total	9	66.67±131.53	16.67±46.38	75.00	0.60
PUR	Unimproved	7	602.86±687.33	298.57±397.51	50.47	0.31
	Improved	1	1 510	10	99.34	2.18
	Total	8	716.25±712.60	262.5±381.90	63.35	0.44
Waterguard	Unimproved	9	1458.89±1680.61	192.22±192.73	86.82	0.88
	Improved	1	1000	300	70.00	0.52
	Total	10	1413±1591.13	203±184.88	85.63	0.84
Ceramic Filter	Unimproved	3	4816.67±4128.05	4200±4156.92	12.80	0.60
	Improved	7	132.86±216.77	1.43±3.78	98.92	1.97
	Total	10	1538±2989.49	721±2400	53.12	0.33

A.Mean/100ml ±SD at collection: Arithmetic mean *E.coli* /100 concentration ±Standard Deviation at collection;

% reduction:Percentage reduction between arithmetic means of collection and storage container samples (negative value indicates increase)

Log reduction value : log10 (Pretreatment concentration) - log 10 (Post treatment concentration) (Sobsey *et al* ., 2008, WHO, 2008)

Appendix 6.7 Arithmetic means, percentage and log reductions of *E. coli* in drinking water samples from collection and storage containers (before and after treatment) with HWTS technologies (2nd assessment).

Technology	Water source category	No. of sampled household collection and storage containers	A.Mean *E. coli* /100ml ±SD at collection	A.Mean *E. coli* /100ml ±SD at storage	% reduction	Log reduction value
Aquatab	Unimproved	3	60±55.68	0	100	>1.78
	Improved	6	76.67±89.59	0	100	>1.88
	Total	9	71.11±76.56	0	100	>1.85
PUR	Unimproved	8	62.5±106.07	0	100	>1.80
	Improved	0				
	Total	8	62.5±106.07	0	100	>1.8
Waterguard	Unimproved	10	937.5±669.62	1195.05±69.86	-27.47	-0.11
	Improved	0				
	Total	10	937.5±669.62	1195.05±69.86	-27.47	-0.11
Ceramic Filter	Unimproved	7	7200±0	0	100	>3.86
	Improved	3	3.33±5.78	150±259.81	-4404	-1.65
	Total	10	5041±3476.32	45±142.30	-33.53	-0.255

Appendix 6.8 Arithmetic means, percentage and log reductions of *E. coli* in drinking water samples from collection and storage containers (before and after treatment) with HWTS technologies (3rd assessment)

Technology	Water source category	No. of sampled household collection and storage containers	A.Mean *E. coli* /100ml ±SD at collection	A.Mean *E. coli* /100ml ±SD at storage	% reduction	Log reduction value
Aquatab	Unimproved	3	3.33±5.77	3.33±5.77	0.00	0.00
	Improved	6	183.33±3.95.71	23.33±32.66	87.27	-0.90
	Total	9	123.33±325.54	16.67±27.84	86.48	-0.87
PUR	Unimproved	7	1302.86±1518.96	85.71±164.51	93.42	-1.18
	Improved	1	50	100	100+	0.30
	Total	8	1146.25±1474.39	87.5±1.5239	92.37	-1.12
Waterguard	Unimproved	10	343±323.17	100±115.47	70.85	-0.54
	Improved	0				
	Total	10	343±323.17	100±115.47	70.85	-0.54
Ceramic Filter	Unimproved	6	221.67±315.68	16.67±40.82	92.48	-1.12
	Improved	0				
	Total	6	221.67±315.68	16.67±40.82	92.48	-1.12

Appendix 6.9 Arithmetic means, percentage and log reductions of Total coliforms in drinking water samples from collection and storage containers (before and after treatment) with HWTS technologies (1st assessment).

Technology	Water source category	No. of sampled household collection and storage containers	A.Mean Total coliforms /100ml ±SD at collection	A.Mean Total coliforms /100ml ±SD at storage	% reduction	Log reduction value
Aquatab	Unimproved	**3**	1426.67±952.96	396.67±185.83	72.20	0.56
	Improved	**6**	815±1007.13	163.33±339.10	79.95	0.70
	Total	**9**	1018.89±976.99	241.11±306.78	76.34	0.63
PUR	Unimproved	7	6492.86±6398.40	2762.86±1863.37	54.45	0.37
	Improved	1	4290	700	83.68	0.79
	Total	8	6217.5±5974.74	2505±1872.98	59.71	0.39
Waterguard	Unimproved	9	16892.22±12960.90	12768.89±12289.89	24.41	0.12
	Improved	1	28000	1030	96.32	1.43
	Total	10	18003±12714.49	11595±12167.13	35.59	0.19
Ceramic Filter	Unimproved	3	6506.67±4128.05	5290±5091.17	18.70	0.09
	Improved	7	1567.14±618.92	611.43±677.01	60.98	0.41
	Total	10	3049±3120.14	1651.11±2946.09	45.85	0.27

Appendix 6.10 Arithmetic means, percentage and log reductions of Total coliforms in drinking water samples from collection and storage containers (before and after treatment) with HWTS technologies (2nd assessment).

Technology	Water source category	No. of sampled household collection and storage containers	A.Mean Total coliforms/100ml ±SD at collection	A.Mean Total coliforms/100ml ±SD at storage	% reduction	Log reduction value
Aquatab	Unimproved	3	2270±225.17	80±80	96.48	1.45
	Improved	6	661.67±712.00	1.67±4.08	99.74	2.60
	Total	9	1197.78±988.03	27.78±56.08	97.68	1.63
PUR	Unimproved	7	7125±5562.31	2912.5±5313.174	59.12	0.39
	Improved	1				
	Total	8	7125±5562.31	2912.5±5313.174	59.12	0.14
Waterguard	Unimproved	10	14575±2380.73	1183±1753.89	91.88	1.09
	Improved	0				
	Total	10	14575±2380.73	1183±1753.89	91.88	1.09
Ceramic Filter	Unimproved	7	8890±0	494.29±561.48	94.44	1.25
	Improved	3	1693.33±5.77	1280±1122.63	24.41	0.12
	Total	10	6731±3476.32	730±796.42	89.15	0.96

Appendix 6.11 Arithmetic means, percentage and log reductions of Total coliforms in drinking water samples from collection and storage containers (before and after treatment) with HWTS technologies (3rd assessment).

Technology	Water source category	No. of sampled household collection and storage containers	A.Mean Total coliforms/100ml ±SD at collection	A.Mean Total coliforms/100ml ±SD at storage	% reduction	Log reduction value
Aquatab	Unimproved	3	1246.67±1086.57	976.67±800.02	21.66	0.11
	Improved	6	443.33±344.36	243.33±201.85	45.11	0.26
	Total	9	711.11±728.43	487.78±565.61	31.41	0.16
PUR	Unimproved	7	14745.71±4734.04	5142.86±152.39	65.12	0.46
	Improved	1	11750	20	99.83	2.77
	Total	8	14371.25±4509.23	4757.5±6964.68	66.90	0.48
Waterguard	Unimproved	10	19567±8283.08	3475±5171.89	82.41	0.75
	Improved	0				
	Total	10	19567±8283.08	3475±5171.89	82.24	0.75
Ceramic Filter	Unimproved	6	95730±75970.48	4300±7485.99	95.51	1.35
	Improved	0				
	Total	6	95730±75970.48	4300±7485.99	95.51	1.35