Siphon Filter Assessment for Northern Ghana

by

Sara Elizabeth Ziff

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Whitman College

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Signature of Author: ______________________________
Sara Ziff
Department of Civil and Environmental Engineering
September 8, 2008

Certified by: ______________________________
Susan Murcott
Senior Lecturer of Civil and Environmental Engineering
Thesis Supervisor

Accepted by: ______________________________
Dr. Daniele Veneziano
Chairman, Departmental Committee for Graduate Students

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ABSTRACT

The siphon filter is a household water filter developed by the Basic Water Needs Foundation based on the design of ceramic candle filters. The siphon filter is marketed under brand names CrystalPur and Tulip and is sold for roughly US$10. An independent Dutch laboratory found log reductions of 4.4-5.5 for the filter, and the filter features flow rates of roughly 3-5 liters per hour.

This thesis evaluates the viability of the siphon filter for households in Northern Ghana, where water-borne diseases are a serious issue. With the help of Pure Home Water, a social enterprise that sells household water treatment and safe storage technologies in Northern Ghana, a field study was conducted in twenty-four (24) households in this region. The study consisted of household visits, water quality analysis and an Effective Use survey, which determined how properly the technology was used. Households drinking low and high turbidity source waters were studied, from a mix of middle and lower class households. A preparatory study was conducted at a MIT laboratory prior to the Ghana field study in order to be most effective during the field study.

Initially, the field study was designed to avoid recontamination of siphon filtered water samples by taking filtered water samples directly from filter taps rather than sampling lower (post-filtration) container water. However, six (6) of forty-eight (48) filtered water samples showed higher levels of contamination than household stored water samples, indicating that recontamination occurred despite sampling directly from taps. Two possible causes of recontamination included bacterial regrowth within the filter, and filter taps resting in dirty lower water containers or touched by dirty hands. Recontamination is believed to have been due to the latter cause, but further research is needed to confirm this conclusion.

The average percent removal of total coliform was 90.7%, and the average positive percent removal for *E. coli* of 94.1% (these values do not include the five and three samples respectively showing negative percent removals for total coliform and *E. coli*). However, these values may have been affected by recontamination and true filter performance may have been more effective. A post-filtration safe storage container design is recommended for the siphon filter to maintain the microbial quality of filtered water, and additional testing of the siphon filter with a safe storage container is advised.

The distinction between middle and lower class households was not found to influence how effectively the filter was operated. Use of high turbidity water was found to affect filter performance in households: the filter clogged frequently with high turbidity water, partially because study participants did not consistently maintain the filter. Filter maintenance is less

crucial for households drinking low turbidity water, and the filter clogged infrequently for these households, even with little maintenance.

Alternative household water treatment technologies are compared to the siphon filter for use in households drinking low and high turbidity source waters in Northern Ghana. These technologies include chlorine, alum (coagulation), and the *Kosim* ceramic pot filter. If the siphon filter recontamination issue were resolved, the siphon filter would be recommended for households drinking low turbidity water in Northern Ghana over the other treatment options considered. The siphon filter is recommended over chlorine for low turbidity water because chlorine is consumable and requires a substantial wait for treated water, while the siphon filter is more permanent and requires little wait for treated water. Alum plus chlorine treatment is recommended for most households drinking turbid water, with the siphon filter as an alternative treatment method for households desiring a more permanent treatment technology, again if the siphon filter recontamination issue were resolved. The siphon filter is preferred over the *Kosim* filter because while the *Kosim* filter can only be cleaned by scrubbing and features a slow flow rate, the siphon filter can be kept clean by other methods (e.g. backwashing) before scrubbing is needed, and has a considerably faster flow rate.

Thesis Advisor: Susan Murcott
Title: Senior Lecturer of Civil and Environmental Engineering

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

BWN	Basic Water Needs Foundation
CFU	Coliform Forming Units
CR	Charles River
E. coli	*Escherichia coliform*
GDWQ	*Guidelines for Drinking Water Quality*
HSW	Household Stored Water
HWTS	Household Water Treatment and Safe Storage
IU	Instructions of Use
JMP	Joint Monitoring Program
MDG	Millennium Development Goals
MIT	Massachusetts Institute of Technology
NTU	Nephelometric Turbidity Unit
PHW	Pure Home Water
SFFS	Siphon Filter Fact Sheet
SFW	Siphon Filtered Water
SODIS	Solar Disinfection
TWF	Tulip Water Filter
UNICEF	United Nation's Children's Fund
WHO	World Health Organization

1. Introduction

1.1 Clean Water Supply in Developing Countries[1]

Access to safe drinking water is critical to maintaining good health. The World Health Organization (WHO) and United Nation's Children's Fund (UNICEF) Joint Monitoring Programme for Water Supply and Sanitation estimate that 1.5 million children will die of diarrheal disease this year resulting from the lack of access to sanitation (JMP, 2008). The water-borne disease rate is much higher than this figure if other water-related illnesses due to pathogenic microorganisms such as guinea worm, cholera, typhoid and schistosomiasis are considered. Additionally, access to safe water and sanitation is fundamental to gender equity, as 71% of household water is collected by women or girls (JMP, 2008). Figure 1.1 shows the percentage of population, by country, with access to safe water.

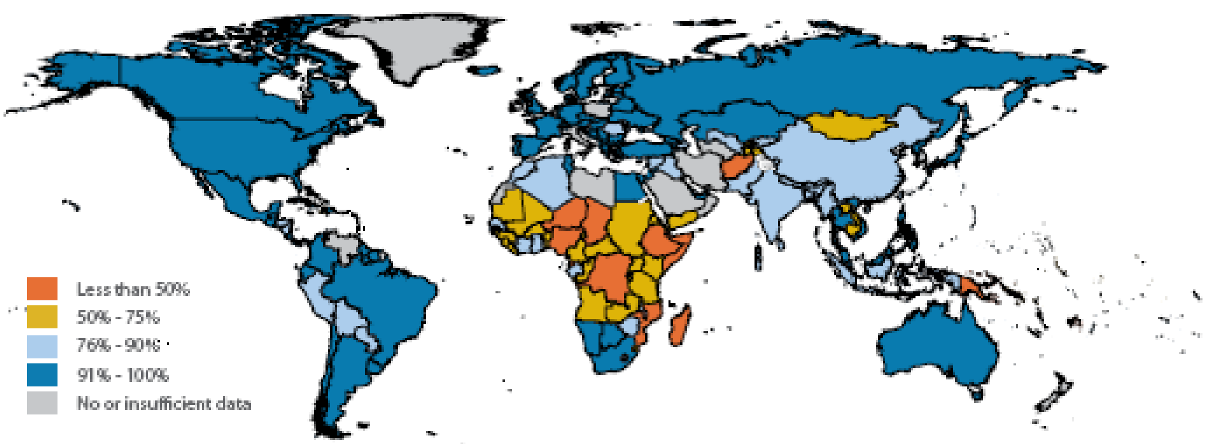

Figure 1.1 Global Drinking Water Coverage 2006 (WHO-UNICEF JMP, 2008)

In a move to eradicate poverty the United Nations set eight Millennium Development Goals (MDG) to meet the needs of the world's poorest by 2015 (UN, 2008a). Under Goal 7: Environmental Sustainability, Target 10 is to "Halve, by 2015, the proportion of people without sustainable access to safe drinking water and sanitation" (UN, 2008a). Since the implementation of the MDGs, it is estimated 1.6 billion people have gained access to safe water (UN, 2008b), however, it is estimated that 784 million people worldwide need to gain access to safe drinking water in order for the drinking water goal to be met (JMP, 2008). Even assuming this goal is met, the world will still be millions of people short of "Clean Water for All," as 11% of the population in developing regions will still lack access to safe drinking water. Information to date indicates that Sub-

[1] Sections 1.1-1.3 adapted from Konyurima Consultancy's joint proposal submitted to MIT in December 2008.

Saharan Africa is making the slowest progress towards meeting the MDG target, making up one third of the population still needing safe drinking water (JMP, 2008).

1.2 Clean Water Supply in Ghana

1.2.1 Ghana Country Profile

Ghana is a West African country bordered to the north by Burkina Faso, to the west by Côte d'Ivoire, and to the east by Togo. It has a population of 23 million people. The climate in the Northern Region is dry and hot, while the climate in the South is more humid. Agriculture accounts for 37.3% of total GDP and 56% of the labor force is employed in farming. Ghana is rich in natural resources and its industries include mining and lumbering (CIA, 2008). The life expectancy in Ghana is 59 and 60 years respectively for men and women (Ansah, 2006). Figure 1.2 shows the Northern Sector of Ghana. The field study for this thesis was conducted in the city of Tamale, which is the capitol of the Northern Region.

1.2.2 Clean Water Situation

Ghana currently suffers from shortages in clean drinking water, particularly in the Northern Region, where fifty percent of people use unimproved sources of drinking water. This figure is ten percent higher than the average for the Sub-Saharan African region where forty percent lack access to an improved drinking water supply (UN, 2008b). As a result, incidence of water-borne disease is high. Water-borne diseases in Ghana include diarrhea, hepatitis A, typhoid, cholera and guinea worm. While guinea worm has been eradicated in almost all places in the world, Ghana still experienced 501 cases in 2008 (CDC, 2009), the second highest rate in the world, after Sudan.

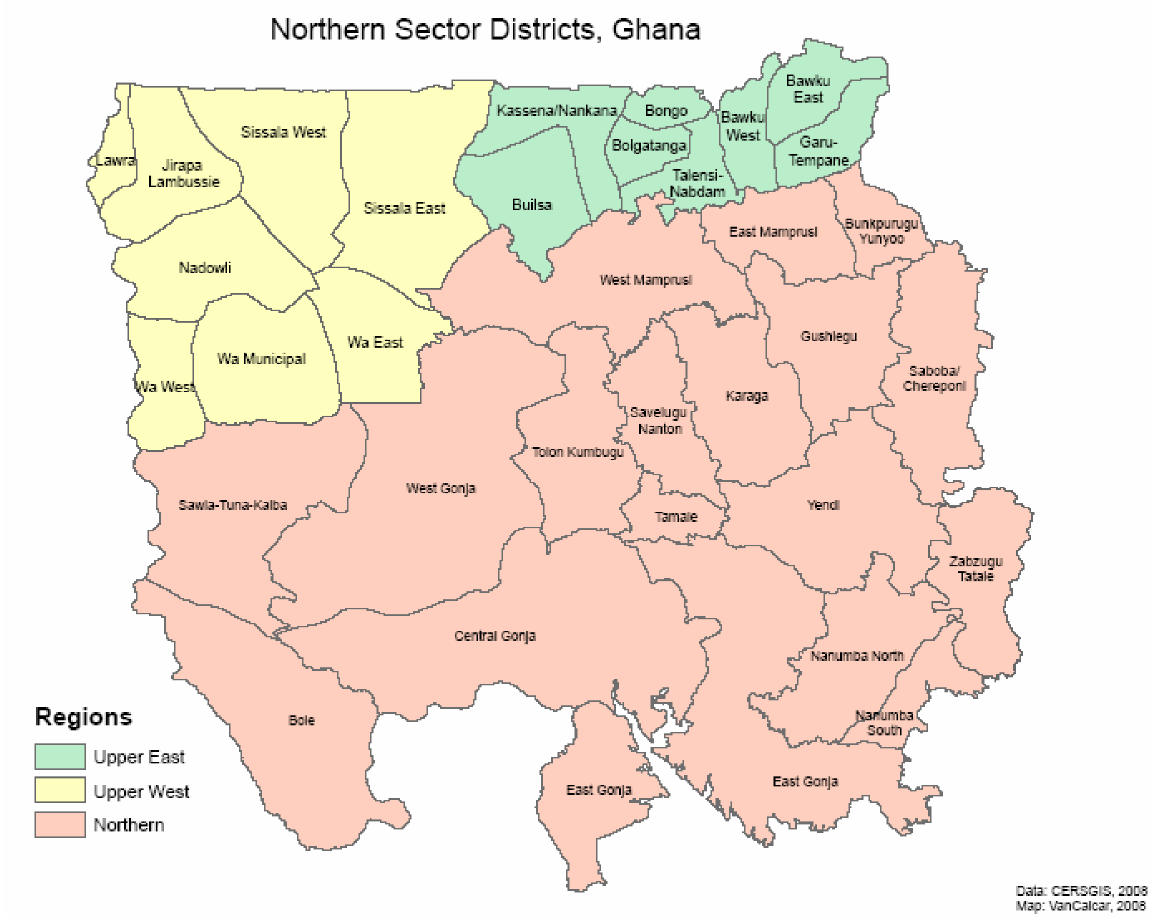

Figure 1.2 Map of Northern Sector districts of Ghana (VanCalcar, 2008)

Waterborne diseases are spread through contaminated drinking water supply and through inadequate sanitation and hygiene practices. In the Northern Region, 37.5% of people use unprotected ponds, lakes or streams for drinking water supply. This problem is exacerbated by a lack of safe sanitation, again particularly in the Northern Region where only 22% have adequate sanitation. Diarrhea, which can result in severe dehydration, is a major contributor to morbidity and mortality of children under the age of five. Incidence of diarrhea in the Northern Sector of Ghana ranges between 15% and 27% in this age group (Ansah, 2006). The goal of this thesis is to address this pressing issue and to help bring clean drinking water on a household and community scale to Northern Ghana.

1.3 Applicability of Siphon Filter Research to Pure Home Water

1.3.1 Pure Home Water

Pure Home Water (PHW) is a social enterprise founded in 2005 by Susan Murcott and local partners in Ghana. PHW is the first organization of its kind seeking to disseminate and scale up household drinking water treatment and safe storage in the challenging environment of Northern Ghana, a region with high poverty rates, low population density, multiple tribes and local languages, strong religious identities – Christian, Muslim, Animist – water scarcity, and limited infrastructure. As a social enterprise, Pure Home Water operates on a break-even basis with retained earnings being fully reinvested into its work in the form of product improvements, outreach and training, and capacity building.

1.3.2 Pure Home Water Organizational History

After receiving start-up funds from the Conrad N. Hilton foundation in 2005, Pure Home Water (PHW) began selling a range of household water treatment and safe storage (HWTS) products in the Northern regions of Ghana including candle filters, safe storage containers and ceramic pot filters. During this time, PHW struggled with a lack of local management capacity and a general lack of awareness of and trust in HWTS. In response to these issues, PHW decided to concentrate on promoting and distributing a single HWTS product in order to gain the focus necessary to succeed. Accordingly the product line was narrowed to the Potters for Peace-type ceramic pot filter, which is locally branded as the *Kosim*[2] filter. Subsequently from 2006-2008, PHW focused solely on demand generation and sale of the *Kosim* filter.

PHW has faced many challenges and has taken some important steps to establish its organization, management and presence in the Northern Sector of Ghana. In 2007, PHW hired a managing director, a field manager and several new sales staff to cope with distribution and sales growth. As a result the *Kosim* filter can currently be found in over 14,000 households in Northern Ghana, providing safe drinking water to over 100,000 people. Moreover, PHW has monitored filters in over 1,000 households during June to August 2008, gaining valuable feedback from customers as to how to improve the *Kosim* filter and outreach.

But while PHW currently promotes and markets the *Kosim* filter, a mid-term goal is to market a variety of drinking water products successfully so that consumers have a range of choices. To this end Master of Engineering students from the Massachusetts Institute of Technology (MIT) (Cambridge, Massachusetts, USA) support PHW with research, development, monitoring social impact and business studies. In the past this has included testing of existing products and actively researching potential new products to add to PHW's product line. This research is accessed on the Web at: http://web.mit.edu/watsan/project_ghana.htm. This thesis researches the siphon filter as a possible product for PHW to market in Northern Ghana.

1.4 Previous Engineering Studies on Ceramic Water Filters

1.4.1 Previous Studies of Ceramic Pot and Candle Filters

Several studies have focused on ceramic water filters' performance in the laboratory and in field settings. Most of these studies feature ceramic pot filters or ceramic candle filters because these are the most widely used ceramic filters. The siphon filter is a new ceramic

2 *Kosim* is a Dagbani word meaning "water from a ceramic pot" and "the best water." It is the drinking water that is served to guests.

filter that takes inspiration from the designs of both the pot and candle filters. As the filter elements of all three types of filters are based on filtration through a porous ceramic medium, a review of study findings based on these pre-existing technologies is useful. Section *2.4 Previous Study of the Siphon Filter by the Delft Institute of Technology* discusses of a previous study of the siphon filter.

1.4.1.1 Role of Silver

Most ceramic filters studied contained colloidal silver or silver nitrate as an antimicrobial agent. Daniele Lantagne, Principal of Alethia Environmental and Lecturer in Civil and Environmental Engineering at Massachusetts Institute of Technology, studied ceramic pot filters with pore sizes ranging from 0.6-3.0 microns and found that some filters without silver let *Escherichia coli* bacteria through. Lantagne attributed *E. coli* removal in these cases to the small pore size of the filters and concluded that silver was necessary for the complete inactivation of *E. coli*. Lantagne found that painting colloidal silver onto the filters did not affect the filtration rate of the filter, or the pH or conductivity of the filtered water (Lantagne, 2001). The World Health Organization found that the only known effect of silver in the body was argyria, a condition in which skin and hair are discolored by silver in the tissues. In order to prevent argyria the WHO recommends that "where silver salts are used to maintain the bacteriological quality of drinking-water, levels of silver up to 0.1 mg/litre can be tolerated without risk to health" (WHO, 2006). No filtered water sample in Lantagne's study exceeded this guideline value, indicating that silver can be safely used to deactivate microbes (Lantagne, 2001).

1.4.1.2 Coliform Removal Performance

Joe Brown and Mark Sobsey of the University of North Carolina School of Public Health studied silver-treated ceramic pot filters in Cambodian households. They found *E. coli* reductions of up to 99.99% with a mean reduction of 95%, and a mean reduction of 90% for total coliform. Brown and Sobsey noted that 17% of field samples contained higher *E. coli* concentrations than untreated water, and attributed this to contamination of storage containers by improper cleaning and handling practices (Brown and Sobsey, 2006). Brown found slightly higher mean *E. coli* reductions of 99% (as opposed to 95% found earlier) both in the lab and in the field in a later study, with reductions of up to 99.9999% (Brown, 2007).

Amber Franz studied several brands[3] of ceramic candle filters with and without silver for her Master of Engineering thesis at Massachusetts Institute of Technology. She tested the filters on water in Kenya with high coliform concentrations and found all of the filters removed *E. coli* at mean values of over 99%. Franz recommended sedimentation before filtration for water with high turbidity levels. The filters removed 91% to 99.95% of *E. coli* and 94.9% to 99.9% of total coliform when tested using Cambridge, Massachusetts Charles River water that contained much lower microbial concentrations. Franz found the candle filters that worked best to remove *E. coli* did not contain silver, and she attributed this removal to very small pore sizes (Franz, 2005).

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[3] Candle filter brands studied were AquaMaster (Piedra candle), Doulton Super Sterasyl, Stefani São João, Pelikan, and Pozzani candles (Franz, 2005).

In 2006 Rachel Peletz conducted a baseline and epidemiological survey of modern urban households in the Northern Region of Ghana for her Master of Engineering thesis project at MIT. The following year, Sophie Johnson continued the survey for traditional rural households in the same region for her MIT Master of Engineering thesis project. These studies found 85% and 99.7% removal of *E. coli* for modern and traditional households respectively, and 90% and 99.4% removal respectively for total coliform (Peletz, 2007).

1.4.1.3 Factors Affecting Use

Ceramic pot filters have been shown to be effective long-term, although effectiveness depends on continued use and breakages. Brown and Sobsey found that microbial effectiveness was not closely related to time in use (Brown and Sobsey, 2006), and Brown found that filters worked effectively up to 44 months in field use (Brown, 2007). Lantagne found that filters as old as 7 years removed 100% of fecal and total coliform (Lantagne, 2001). Brown and Sobsey studied rates of disuse of ceramic filters in Cambodia and found a 2% rate of filter disuse per month, largely due to breakages. Continued use was associated with hygiene, water and sanitation practices in the home, cash investment in the technology by the household and use of surface water as a primary drinking water source (Brown and Sobsey, 2006).

1.4.1.4 Ceramic Filter Use and Diarrhea Disease Incidence

Several studies found a correlation between ceramic filter use and reduced diarrhea incidence. Martella du Preez of the Council for Scientific and Industrial Research in South Africa and others studied incidence of diarrhea in Zimbabwe and South Africa and found that ceramic Doulton/Berkefeld[4] candle filters impregnated with silver reduced the incidence of both bloody and non-bloody diarrhea by 80%. The authors noted that this large reduction may have been due in part to the study heightening awareness of water contamination and hygiene practices (du Preez et al., 2008). Brown and Sobsey found a 46% reduction in diarrhea in their study of ceramic pot filters in Cambodia (Brown and Sobsey, 2006). This correlates well with Brown's later findings of roughly 40% diarrhea reduction (Brown, 2007). Peletz and Johnson found that ceramic pot filters reduced the incidence of diarrhea by 88% for modern urban households and by 69% for traditional rural households in the Northern Region of Ghana. Johnson attributed this discrepancy between modern and traditional household values to factors such as access to sanitation facilities, better hygiene practices, and higher level of mother's education found in modern urban households as compared to traditional rural households (Peletz, 2007).

1.4.1.5 Turbidity and Flow Rates

In addition to studying the effect of ceramic candle filtration on *E. coli* and total coliform, Franz also studied turbidity removal and flow rates of the candle filters. Franz found mean turbidity reductions of 97% to 99% for water in Kenya and mean reductions of 88% to 94% for Charles River water. In both cases finished water had turbidities of below 1 NTU on average. The WHO recommends a mean turbidity of 0.1 NTU for adequate disinfection, but proposes no health-based guideline value. A value of 5 NTU is suggested to usually be acceptable for customers (WHO, 2006). The candle filters were

[4] This brand of ceramic candle filter is atypical in that it is made of diatomaceous earth rather than clay.

therefore reasonably effective at removing turbidity from both high- and low- turbidity waters. Franz found flow rates for individual candle filters from 0.035 to 0.454 L per hour for water in Kenya. Flow rates decreased with time, possibly due to filter clogging and/or decreased hydraulic head from the water level decreasing in the source bucket. The maximum flow rate found for an individual candle filter corresponded to 4.8 L per day, which was not sufficient to meet the 7.5 L per day recommended by the WHO (WHO, 2006). Franz suggested that allowing particles to settle before filtration may increase flow rates for highly turbid waters. The filters had higher flow rates when they were tested with low turbidity Charles River water. The maximum flow rate found was 0.546 L per hour for a single candle filter, which is equivalent to 13.1 L per day assuming a regular filter feeding rate. This is just enough water to support two people, assuming the filter does not clog and the water level remains high (Franz, 2005).

1.4.1.6 Virus Removal Performance

Although ceramic filtration has been shown to remove turbidity and coliforms effectively and to reduce incidence of diarrhea, demonstrated effectiveness for removing viruses has been mixed and studies are limited. Lantagne found only an 18.7% reduction of MS2 coliflages by ceramic pot filters with 0.6 to 3.0 μm pore size, and hypothesized that the 0.025 μm viruses easily traveled through the filters (Lantagne, 2001). Similarly, Franz found the Pelican brand candle filter was ineffective at removing MS2 coliflages (Franz, 2005). However, Brown achieved an MS2 reduction of 90% to 99% in laboratory testing of ceramic filters with and without silver (Brown, 2007). These mixed results suggest possible variation in virus removal effectiveness depending on filter type, and more testing is needed to determine which parameters effect virus removal.

1.5 Research Objectives

This study seeks to determine the viability of (second version[5]) siphon filter use by lower and middle class households in Northern Ghana drinking turbid and non-turbid waters. Filter use by these households has been assessed using water quality tests and an Effective Use survey, in order to evaluate how properly the technology is operated and maintained in households. Based on the findings of this study the author will advise Pure Home Water regarding which of these household types and water quality conditions (turbid vs. non-turbid) would be suitable markets for the siphon filter.

[5] Section *2.3 Basic Water Needs Product Development* explains the differences between the three versions of the siphon filter.

2. The Siphon Filter

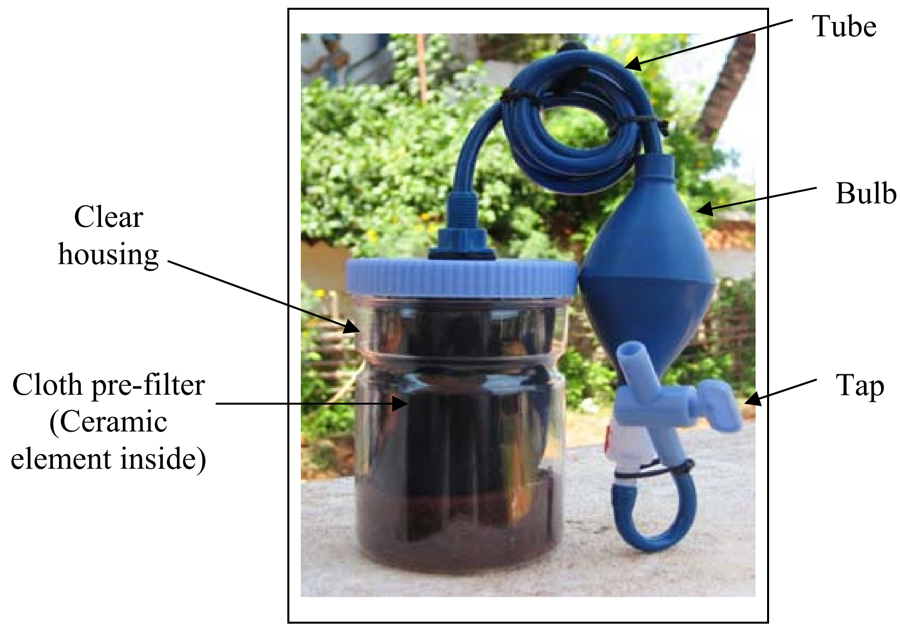


Figure 2.1 The siphon filter (BWN-SFFS, 2008)

The siphon filter was developed by the Basic Water Needs Foundation, a Dutch non-governmental organization. The filter, shown in Figure 2.1, is marketed using brand names CrystalPur and Tulip. Basic Water Needs founded Basic Water Needs India, which manufactures the filter in Kottakuppam, India[6]. Basic Water Needs India distributes the filter within India and exports the filter to Southeast Asia and East Africa. (BWN-SFFS, 2008). The filter retails for approximately US$8-12, and a replacement ceramic filter element costs approximately US$3-4 (BWN-SFFS, 2008). The siphon filter is based on the design of candle filters. Candle filter elements are hollow cylinders of ceramic material capped at the top with ceramic and at the bottom with an outlet tube that trap drinking water contaminants when water flows through small pores in the filter (Figure 2.2). This candle filter (or filters) is placed in the top container of a two-container system, in which water flows from the top (contaminated water) compartment through the candle filter element to the bottom (clean water) compartment (Figure 2.3). Because

[6] Contact information:
Basic Water Needs India Pty. Ltd.
Thivan Kanthapa Nagar
Plot 116-117
Peryamudaliyar Chavadi
Kottakuppam Post 605104 Tamil Nadu (India)
Tel +91-(0)413-2623963 Mob +91-(0)9786989104
Email: bwnindia@gmail.com

candle filters rely on gravity to create pressure to transport water through the filter, flow rates are typically slow.

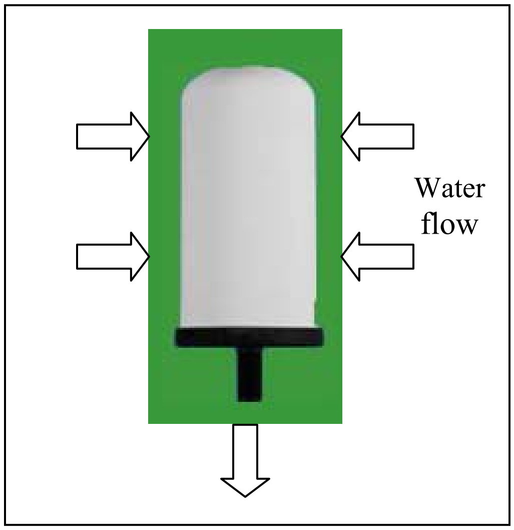


Figure 2.2 Candle filter element (Ecosystems International, 2009)

Figure 2.3 (a) Candle filter system (Glacier, 2009); (b) Interior view of system (SRV Pty Ltd, 2009)

Basic Water Needs used the siphon effect to improve the flow rate through the candle. The siphon filter has a flow rate of approximately 3-5 liters per hour (BWN-SFFS, 2008), which is several times faster than traditional candle filters for which flow rates range from 0.14-0.55 liters per hour per individual candle (Franz, 2005).

The Dutch laboratory Waterlaboratorium Noord found a log 4.4 – 5.5 removal rate of the siphon filter for *E. coli* bacteria, which were used as an indicator organism for filter performance (Wubbels, 2008). This removal rate was found even after passing 7,000 liters of water through the filter. Virus removal for the siphon filter has not been established; due to the small size of these organisms, it is expected that viruses may pass through the filter.

The manufacturer states that the ceramic element can filter approximately 7,000-10,000 liters before needing to be replaced, depending on the turbidity of the water. This corresponds to roughly 1-1.5 years of use for a family of 2.5 people with a daily per person water usage of 7.5 L per day (BWN-SFFS, 2008; WHO, 2006). When used with extremely turbid source waters, this lifetime may be shorter. Basic Water Needs does not state an estimated lifetime for filter parts (e.g. tube, bulb, tap) other than the ceramic element. The filter is designed to be used out of direct sunlight, which degrades these plastic parts. A new, third version[7] of the siphon filter is currently being developed to withstand five (5) years of use in full sun (van der Ven, personal communication, 2008); however, the product evaluated for this study in Ghana is the first widely distributed commercial version of the filter (second version).

A diagram of the siphon filter set-up is shown in Figure 2.4. To use the siphon filter, the ceramic filter element is removed from its plastic housing and placed in the user's own household water storage container. This upper container is ideally elevated to table height, approximately 70 cm above the height of a lower container for filtered water. The lower container is also the user's own. The filter tube transports water from the upper to lower container. Flow rate for the filter is greatest with a large distance between the upper container water level and the level of the filter tap. If the upper container water level sinks below the level of the tap (which is typically impossible with a raised upper container), water will cease to flow.

[7] Section *2.3 Basic Water Needs Product Development* explains the three versions of the siphon filter. The current (as of May 2009) version of the filter is the second version.

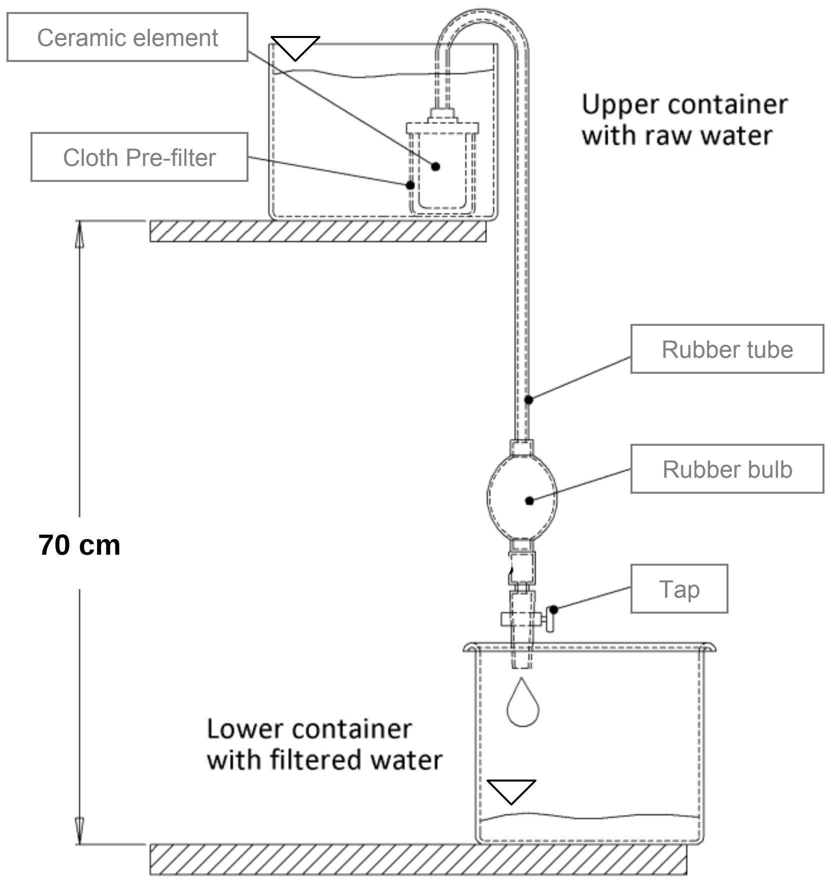


Figure 2.4 The siphon filter set-up (Tanzaniaqua, 2008)

2.1 Filter Components

2.1.1 Ceramic Filter Element

The ceramic filter element is comparable in design to a candle filter element. Small pores in the ceramic material allow the passage of water, but trap microorganisms. The siphon filter element is made of diatomaceous earth, which is a chalk-like, soft rock with fine pores (USGS, 2009). Diatomaceous earth filter elements typically have pore sizes ranging from 0.1-10 µm (Bershteyn, 2005).

The filter element is impregnated with silver, which serves as an antimicrobial agent to prevent bacterial growth[8]. Filtration through the ceramic element removes bacteria and protozoa, and silver deactivates some of the organisms that pass through the filter. Residual silver has not been shown to effectively protect against recontamination of filtered water since silver is slow-acting (WHO, 2006), but silver may prevent bacterial growth on the filter's surface (Doulton, 2009). Silver concentrations in siphon filtered

[8] The specific type of silver impregnation of the siphon filter element is neither colloidal silver nor silver nitrate soaking, but is a Basic Water Needs company secret (van der Ven, 2009).

water range from 2.5–6.5 µg per liter (Tamijesselvan, 2008). The WHO does not establish a guideline value for silver in drinking water, though it states that in situations in which silver is used to deactivate bacteria in drinking water, levels of up to 100 µg per liter could be tolerated without risk to health (WHO, 2006).

Basic Water Needs recommends filtering 20 liters of water through the filter before drinking the filtered water. This is because particles may leach from the ceramic element during its first period of use, possibly causing unpleasant-tasting and slightly cloudy water. Ceramic leaching is an aesthetic issue and should not affect the safety of the drinking water (Murcott, 2009).

2.1.2 Cloth Pre-filter

A cloth pre-filter prevents premature clogging of the ceramic element by preventing large particles from reaching the element. The pre-filter can be removed and washed by hand when it becomes dirty.

Figure 2.5 Cloth pre-filter (van der Ven-TWF, 2008)

2.1.3 Tube, Bulb, and Tap

A rubber tube carries water from the ceramic element in the upper (contaminated) water container to the lower container for filtered water. When pressed, a bulb located near the end of the tube starts a siphon by creating a vacuum that draws water from the upper container to the lower container. Water continues to flow on its own due to the siphon effect. When the ceramic filter element is dry when first used, the user must press the bulb several times before water flows. A tap at the end of the tube can be closed or opened to control water flow.

Figure 2.6 Tube, bulb and tap of siphon filter (van der Ven-TWF, 2008)

2.1.4 Scrub Pad

The user can clean the ceramic element using an included scrub pad. Scrubbing removes particles that clog the ceramic element. This process is explained in more depth in the *6.2.2 Cleaning the Filter* section.

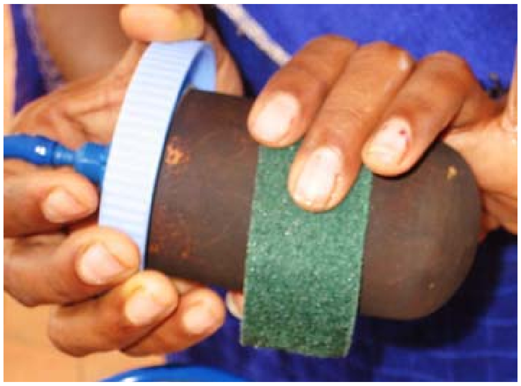


Figure 2.7 Scrubbing the ceramic element with the included scrub pad (van der Ven-TWF, 2008)

2.1.5 End-of-Life Gauge

An included end-of-life gauge indicates when the ceramic element is too thin to work effectively and needs to be replaced. The *Instructions for Use* sheet explains how to replace the ceramic element.

Figure 2.8 Measuring the ceramic element using the end-of-life gauge (BWN-IU, 2008)

2.1.6 Filter Housing

A clear plastic jar houses the filter to protect the ceramic element from breakage during transit, and can be used to store the filter when not in use. The housing should be removed before filter use, in order for water to flow through the filter. The scrub pad is included inside the housing.

2.2 Filter Use

The following *Instructions for Use* guide is adapted from a Basic Water Needs instruction sheet (BWN-IU, 2008). This is a technical guide for users with English literacy; a pictorial guide has also been developed by Courtney Sung (*Appendix A*).

USING YOUR FILTER

1. When source water is visually dirty, let it settle for an hour in your traditional storage vessel to allow particles to sink to the bottom. Pour settled water (top level only) from this vessel into the upper water container for filtration.
2. Remove housing jar and place filter in upper water container full of water to be filtered. Leave cloth pre-filter covering ceramic element.
3. Place tap over lower storage vessel.
4. Open tap and press bulb (see figure). Wait until bulb slowly fills and water starts flowing out of the tap. This has to be repeated a few times when using a dry filter element.
5. Using a new filter element, let the filter element stay in the water during one night and do not use the first 20 liters of filtered water!

Tap is open.

Guidelines for Filtration

- Do not use the filter regularly in full sun.
- If water from the lower container is taken out with a cup, make sure cup and hands are clean.
- Use filtered water the same day. Empty the lower water container each evening into the upper water container to avoid long-term storage of filtered water.
- Pre-treatment of very dirty water using coagulant will lengthen filter life.

CLEANING YOUR FILTER

Pre-filter Washing

When the cloth pre-filter becomes dirty, remove it from the ceramic element and wash it in clean water.

Backwashing

The ceramic element will eventually become clogged due to particles in the contaminated water. This will reduce the water flow. To restore flow, backwash the filter using the following steps:

1. Close tap and press bulb.
2. Wait until the bulb is again filled with water.
3. Open the tap.
4. Repeat a few times if the flow is not increased.

Tap is closed.

- It is advised to backwash the filter once every day.
- Frequent backwashing will result in a longer life of the ceramic element.

Scrubbing the Ceramic Element

If backwashing does not increase the flow, you must scrub the ceramic element.

- Remove the cloth pre-filter, unscrew the lid and scrub the ceramic element using the included scrub pad.
- Remove only as little ceramic material as possible, as ceramic removal will shorten the lifetime of the element.
- Rinse with clean water.
- Store scrub pad in a safe place in your kitchen.

CHANGING YOUR FILTER

When to change your ceramic filter element

- At a certain point, your filter will become too thin to effectively remove bacteria and parasites.
- To check when replacement of the ceramic element is needed:

1. Unscrew the wing nut a few turns and remove the plastic sensor attached to the lid.
2. When the sensor fits around the thinnest part of the ceramic element, the element has become too thin to deliver safe water and has to be replaced.

How to change ceramic element

1. Remove hose from ceramic element by turning and pulling the hose.
2. Hold ceramic element in one hand and unscrew wing nut.
3. Replace old ceramic element with a new ceramic element.
4. Remount wing nut and hose.

Figure: Removing the hose for replacement of the ceramic element.

Figure 2.9 ***Instructions for Use*** **siphon filter technical guide**

2.2.1 Filter Operation

The top section of the *Instructions for Use* guide addresses how to operate a new siphon filter. When water is highly turbid, the manufacturer recommends settling the water for one (1) hour to reduce turbidity before filtration. The filter element (with cloth pre-filter) is removed from its housing and placed in the upper container, and the tap is placed over the lower container. The bulb is pressed to start water flow. When the filter is new, pressing the bulb must be repeated a few times to rid the filter of air before water flows. The manufacturer recommends soaking new filters in water overnight to cause water to flow more readily upon using filters the first time. The manufacturer also recommends discarding the first twenty (20) liters of filtered water, as ceramic particles from the element may leach when the filter is new. The ceramic particles may give an unpleasant taste or appearance to the water, but do not pose a health risk.

The *Guidelines for Filtration* section found in the upper right of the *Instructions for Use* sheet discusses additional factors of filter use: Regular use in direct sunlight is not advised, as this rapidly degrades plastic filter parts. If a cup is used to fetch water from the lower container, the cup and the user's hands should be clean to prevent recontamination of filtered water. In order to maintain microbial water quality of siphon filtered water, at the end of each day extra water from the lower container should be emptied into the upper container to avoid long-term storage. As highly turbid water tends to clog the filter more frequently, resulting in more frequent scrubbing and a shorter life of the filter element, the manufacturer recommends using a coagulant to decrease turbidity before filtration.

2.2.2 Cleaning the Filter

The lower left section of the *Instructions for Use* guide addresses cleaning the siphon filter. When particles build up within the ceramic filter element due to routine filtration, the flow rate decreases. Two mechanisms allow the user to clean the ceramic element to restore the flow rate: backwashing and scrubbing. Additionally, the cloth pre-filter catches large particles before they reach the ceramic element, and this cloth filter can be washed by hand.

To backwash the filter, the user closes the tap and presses the bulb, forcing water currently in the filter out through the ceramic element. This process washes clogged particles out of the filter. Basic Water Needs recommends backwashing once per day to maintain filter flow rate and to extend the life of the filter. When the filter is clogged, the user may need to backwash multiple times to restore the flow rate. To backwash more than once, the user waits after each press of the bulb until the bulb fills again with water.

If backwashing does not restore flow rate, the user can use the included scrub pad to remove a thin layer of ceramic material from the filter element. This action removes clogged particles from the filter, restoring flow rate. The user should scrub off as little ceramic material as possible, as scrubbing thins the filter and eventually reduces its effectiveness.

2.2.3 Filter Replacement

The lower right section of the guide discusses siphon filter element replacement. The included end-of-life gauge indicates when the filter element is too thin to work effectively. This gauge is located underneath the lid of the filter. When the gauge fits around the thinnest part of the ceramic element, the filter is too thin and must be replaced. To replace the filter element, the user removes the tube, unscrews a wing nut on the filter lid and replaces the old filter element with a new one.

2.3 Basic Water Needs Product Development

2.3.1 First Version of Siphon Filter

The siphon filter currently marketed (as of May 2009) is the second version of the filter. The first version of the siphon filter has several differences from the second version:

(1) *Ceramic element* The first version of the siphon filter ceramic element had problems with leakage between the ceramic and the plastic cap. Ceramic elements of the second version of the filter are from a different company, are more durable and feature higher bacterial removal (Holtslag, 2009).
(2) *Tube* The tube connection to the ceramic element was unreliable in the first version.
(3) *Pre-filter* The pre-filter was colored red (rather than blue) and was less tightly woven, presumably allowing more particles to slip through to the ceramic element.
(4) *Plastic housing* The plastic jar housing of the first version of the filter was different.
(5) *End-of-life gauge* The first version of the siphon filter did not include an end-of-life ceramic element gauge as does the current version (van der Ven, 2009).

Basic Water Needs initially gave 800 of the first version of the siphon filter to families and health clinics in Tanzania, Mozambique and Zambia to test the filter, and then sold 4,000 filters to families in Tanzania and Mozambique for less than the full price of the filter while it continued to improve its product (Holtslag, 2009).

2.3.2 Third Version of Siphon Filter

Basic Water Needs is currently developing a new, third version of the siphon filter; a final model of this third version is expected in July 2009. The third version of the siphon filter will include the following changes from the second version:

(1) The rubber ring used to control the length of the tube for the second version of the siphon filter will be replaced with a new part in the third version of the filter, making the role of the tubing easier for the user to understand.
(2) The rubber bulb will be more durable for the third version of the filter due to a different plastic type and manufacturing process, in response to problems with the second version bulb.
(3) The tube of the third version filter will also be made of a more durable plastic type.

(4) The third version filter will feature an integrated tap with a non-return valve.
(5) Basic Water Needs reports that the third version of the siphon filter will be sold for a lower price of roughly US$5 (van der Ven, 2009; Holtslag, 2009).

These changes to the siphon filter should make it more durable, intuitive and affordable to users.

2.4 Previous Study of the Siphon Filter by the Delft Institute of Technology

The Delft Institute of Technology conducted a field study of the first version of the siphon filter in Tanzania, and proposed a redesign of the filter as well as a business plan for marketing the filter in Tanzania (Boezeman, 2008).

The Tanzania field study found that many participants had various troubles operating and cleaning the filter. These issues included the following:

Operating Issues

- *Bulb* Difficulties using the bulb
- *Tap* Difficulties determining whether the tap was open or shut
- *Adjusting Loop* Challenges properly using the loop to adjust the height of the tap relative to the lower container

Cleaning Issues

- *Pre-filter* Misunderstanding the function of the cloth pre-filter
- *Role of Backwashing* Many participants backwashed the filter to rid it of water before storage rather than to clean the filter. Most participants remembered scrubbing as a way to clean the filter, but did not associate backwashing with cleaning the filter.

Recontamination

- Risk of recontaminating filtered water by touching the filter tap with dirty hands

All participants had insufficient understanding of how to clean the filter. Many difficulties operating the filter disappeared after a sustained period of use, but cleaning the filter remained difficult throughout use. Many of the issues found in the Delft Institute of Technology Tanzania study were also encountered in the Ghana field study for this thesis project. Both the Tanzania study and this thesis study conclude that careful attention needs to be paid toward education of the siphon filter product.

Regarding user satisfaction with the filter, nearly all participants were satisfied with the flow rate of the filter and indicated it was sufficient to supply drinking water for their households. All participants enjoyed the “natural” taste of the filtered water as compared to the taste of water after boiling, which participants usually practiced for drinking water prior to filter use. Time saving was most often mentioned as the most important reason for using the filter, as filter use was faster than boiling.

The study made several suggestions for a redesign of the siphon filter. Several proposed changes to the filter were addressed by the second version of the filter, but the following suggestions apply to the second version as well as the first:

(1) Design the packaging to show which parts of the filter need to be kept clean to ensure safe drinking water;
(2) Design the packaging box to unfold to reveal a printed arrow the ideal length between upper and lower water containers (i.e. 70 cm), to be used as a guide for filter set-up;
(3) Include a safe storage lower bucket for clean water with a connection in the lid for the filter tap with the filter system, to prevent recontamination of filtered water;
(4) Add to the filter manual the reasons for filtering drinking water and the reasons why some siphon filter parts should be kept clean;
(5) Eliminate the need to filter 20 liters of water before filter use, perhaps by filtering 20 liters in the factory.

The Tanzania study also suggested a new design for the filter tap, to help prevent recontamination of filtered water by dirty taps. The proposed redesigned tap is shown in Figure 2.10. Many study participants touched the tap with dirty hands and then dropped the tap into filtered water, possibly recontaminating the water. The proposed redesigned tap features a larger and rounder tap lever to allow the tap to hook onto a bucket rim, as well as an extra cylindrical covering to protect the tap from contamination by dirty hands.

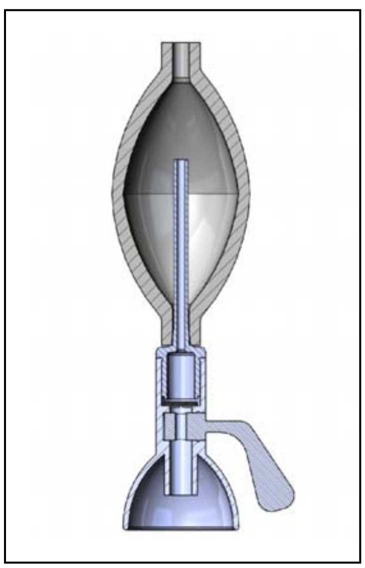


Figure 2.10 Proposed tap redesign by Tanzaniaqua project (Tanzaniaqua, 2008)

This thesis project studies the second version of the siphon filter, applying a water quality analysis and a survey of household use to determine how effectively the filter is received by households in Northern Ghana. The study focuses on rural and urban households drinking turbid and non-turbid waters in Northern Ghana.

3. Research Methods

The siphon filter was studied in a laboratory at MIT during the fall semester and in households in Northern Ghana during the month of January. The study at MIT consisted of water quality testing, and the field work in Ghana featured both water quality monitoring and Effective Use surveying in households.

For the laboratory study at MIT, Charles River Water was mixed with dirt/clay previously brought from Northern Ghana to simulate turbid dam water found in Northern Ghana. This unfiltered raw water was filtered using a new siphon filter. Unfiltered and filtered water was tested to determine contaminant removal. Preliminary tests indicated ceramic filter particle leaching; the manufacturer recommends filtering twenty (20) liters through the filter before use to remove these particles for aesthetic reasons. After conducting the first set of three (3) tests, I filtered twenty liters through the filter before continuing my laboratory study. The purpose of the MIT laboratory work was two-fold. First, the work gave me experience with the laboratory methods that would be used in Ghana in order to maximize my efficiency in Ghana. Second, the purpose was to become familiar with the various features of and operation of the siphon filter, again in order to be effective during the Ghana field period.

The same turbidity and microbial indicator tests were done for the MIT laboratory and Ghana field studies. These water quality tests and the Effective Use survey are explained below.

3.1 Water Quality Monitoring

In order to measure how effectively the filter removed contaminants from source waters, I performed microbial indicator and turbidity water quality tests of household stored water (HSW) and siphon filtered water (SFW). HSW was sampled directly from upper water containers[9] using a 100 ml Whirl-Pak® sampling bag, and SFW was collected directly from filter taps (Figure 3.1) (again using a Whirl-Pak® bag) to avoid possibly-contaminated lower water containers. Unfortunately, contamination of SFW samples may have occurred despite this precaution through filter taps that rested in lower containers. Recontamination of siphon filtered water is discussed in section *5.1.1*.

[9] Household stored water means upper container water for this study. Although households may have stored drinking water in multiple vessels, only the water in the upper container used with the siphon filter was sampled for HSW samples.

Figure 3.1 Collecting a sample from siphon filter tap into Whirl-Pak bag

Samples were tested within four to six (4-6) hours at the laboratory at the Pure Home Water house. The *Standard Methods for the Examination of Water and Wastewater* (20th Edition) indicates that "the shorter the time that elapses between collection of a sample and its analysis, the more reliable will be the analytic results" (Clesceri, 1998). Some countries and studies recommend more lenient guidelines of up to twenty-four (24) hours (Pope, 2003).

The three types of water quality tests that were conducted are described below.

3.1.2 Turbidity Measurement

Turbidity is a measure of the cloudiness of water, which is caused by suspended particles. Particles in water scatter light, and nephelometers are designed to measure the extent of this scattering by using a light beam and light detector set a 90° angle to the beam. With these instruments turbidity is measured in Nephelometric Turbidity Units (NTU). Turbidity is significant for water quality partly because microbes often attach to particles in water. Disinfection of turbid waters can be difficult because these particles often protect microbes from inactivation. The WHO does not set a health-based guideline value for turbidity, but states that the appearance of water with a turbidity of less than 5 NTU is usually acceptable to consumers.

I used a HACH brand 2100 Series portable turbidimeter for turbidity measurements at MIT and in Ghana. This instrument uses the nephelometric principle of measurement, monitoring light scattered by the sample at a detector 90° to the side of the beam. The instrument measures turbidity in the range from 0 to 1,000 NTU; the turbidimeter readout uses NTU's.

3.1.1 Microbial Quantification

Some types of microbes in drinking water cause gastrointestinal illnesses when ingested. Since water filters aim to remove these microbes, water quality tests should show efficacy of a filter by indicating microbe levels before and after treatment. However, water quality tests that measure the presence of these harmful microbes directly are usually complicated and expensive; therefore, *index organisms* are commonly used to infer the presence of fecal contamination. Index organisms can easily be tested for, and their presence implies the presence of harmful microbes. *Escherichia coli* (*E. coli*) are commonly used as an index organism for fecal coliform bacteria and are suitable because they cannot grow outside the body.

The microbial tests used in this research measured total coliform bacteria as well as *E. coli*. Total coliform are used as *indicator organisms* to assess technology performance because *E. coli* are not usually present in source (or treated) water in high enough concentrations to indicate removal efficiencies. This study used *E. coli* as index organisms to measure fecal contamination and total coliform as indicator organisms for filter performance (WHO, 2006).

Two tests were used in conjunction to measure microbial water quality: the IDEXX brand Colilert ® test and the 3M™ brand Petrifilm™ test. Both of these tests measure total coliform and *E. coli* coliform. The tests are specific to *E. coli* because they use a substrate for the Beta-glucuronidase enzyme produced by *E. coli* and not by other coliform bacteria. These tests were chosen for their simplicity. Minimal laboratory equipment is required to run the tests; they can even be incubated by body heat, eliminating the need for an incubator. However, in this work a portable Millipore brand incubator[10] was used for all sample incubation. Both tests are incubated at 35 °C. Additionally, dilution is not needed for either test, eliminating the need for sterile lab equipment other than Whirl-Pak® sample bags and sterile disposable pipettes.

The Colilert ® test measures the presence or absence of total coliform and *E. coli*, using a threshold value of 10 CFU per 100 ml. A negative result for *E. coli* with this test indicates at most a low risk due to *E. coli*, and a positive result indicates at least an intermediate risk. Colilert ® refers to a family of IDEXX products that measure coliform bacteria; the test used in this study is called the 10 ml pre-dispensed Colilert ® MPN Tube. The test requires a 10 ml sample. If the sample tube turns yellow after twenty-four (24) hours of incubation, total coliform are present at a level of 10 CFU per 100 ml or higher. If the tube fluoresces blue after this same period, at least 10 *E. coli* CFU per 100 ml are present, quantifying intermediate risk due to *E. coli*.

The Petrifilm™ test measures total coliform and *E. coli* present in water at a minimum detection level of 100 coliform forming units (CFU) per 100 ml. This level corresponds to a high risk due to *E. coli*, according to the 1997 WHO *Guidelines for Drinking Water Quality* (WHO, 1997). The Petrifilm™ test allows users to count the number of colonies formed by coliform bacteria and to assign a total coliform and *E. coli* level to waters containing at least 100 CFU per 100 ml. The Petrifilm™ test requires only 1 ml of sample. If 1-10 *E. coli* colonies form, this indicates high risk due to *E. coli* (i.e. the equivalent of 100-1000 *E. coli* CFU per 100 ml). Growth of more than 10 colonies indicates very high risk (i.e. greater than 1000 CFU per 100 ml).

[10] Millipore Cat. # XX6310000

By combining the Colilert® and Petrifilm™ tests one can quantify the level of risk due to *E. coli* (see Table 3.1)[11]. If the Colilert® result is negative for *E. coli*, the sample is at most low risk. If the Colilert® test result is positive for *E. coli* while the Petrifilm™ test shows no *E. coli* colonies, the sample indicates an intermediate risk. If the Petrifilm™ test shows 1-10 *E. coli* colonies, the sample indicates high risk, and if this test shows more than 10 *E. coli* colonies, the sample indicates very high risk.

Table 3.1 Risk Levels from *E.coli*

Risk Level	*E.coli* in Sample (CFU per 100 ml)	Colilert® Fluoresces Blue	# Blue Colonies on 3M™ Petrifilm™
Conforms	<1	- (Below detection)	0
Low	1-10	-	0
Intermediate	10-100	+	0
High	100-1000	+	1-10
Very High	>1000	+	>10

(Adapted from WHO, 1997, replacing "thermotolerant bacteria" with "*E. coli*") (Metcalf, 2006)

3.1.1.1 Interpretation of Results

In order to determine the efficiency of the filter in terms of percent and log removal, specific levels of total coliform have been determined. If the Colilert® test shows a negative result, the sample has between 0-9 CFU per 100 ml. In this case, the conservative value of 9 CFU per 100 ml was used for calculations in this study except when noted. If the Colilert® test is negative, then the Petrifilm™ test should also be negative. If a sample has coliform levels of at least 100 CFU per 100 ml, the Petrifilm™ test allows the user to directly read the coliform level from the test by counting the number of colonies. However, if the coliform level of a sample is lower than 100 CFU per 100 ml, the corresponding negative Petrifilm™ result must be used in conjunction with the Colilert® test to approximate the coliform level. The Colilert® and Petrifilm™ tests used in combination can provide only approximate levels of *E. coli* and total coliform in samples with low coliform levels. If the Colilert® test shows positive results and there are no colonies on the Petrifilm™ test, then the sample has between 10-99 CFU per 100 ml. For this study, the conservative estimate of 99 CFU per 100 ml was used for calculations in this case except when noted. Some calculations were performed both with conservative and non-conservative values (i.e. the value 1 CFU per 100 ml for a negative Colilert result paired with a negative Petrifilm result and the value 10 CFU per 100 ml for a positive Colilert result paired with a negative Petrifilm result) in order to express the possible range of percent removal and log reduction values.

For percent removal calculations, sample sets for which both household stored water and siphon filtered water samples showed undetectable levels of coliform contamination were

[11] This combination of risks and their interpretation was first proposed and taught by Professor Robert Metcalf of California State University, Sacramento.

excluded from the analysis. This was the case for nine (9) samples, because the Ghana water company BiWater Joint Venture began providing water to some of the study site communities. This was unexpected because these communities had lacked safe water for many years prior. Log reductions were calculated only for sample sets showing lower contamination levels in siphon filtered water than in household stored water. Sample sets showing increased contamination in treated versus untreated water or showing no contamination removal (10% of total coliform samples and 6% of *E. coli* samples) were dealt with as a separate category.

Correlation coefficients were used to compare the two sample sets taken from each household. This method determined how closely the two sets of data were related. The equation for a correlation coefficient is:

$$Correl(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}}$$

where x and y are the two arrays of data. Correlation coefficients range from 0-1, with 0 indicating no correlation between the data sets.

3.2 Effective Use Surveying

For the field study in Northern Ghana, siphon filters were placed in twenty-four (24) households in or near the city of Tamale. Two Pure Home Water employees distributed the filters from December 13^{th} - 17^{th}, 2009 and explained how to use them to heads of households in charge of household water. The sheet used by PHW distributors is shown in *Appendix B: Siphon Filter Distribution Sheet*. Filters were in households for roughly one month before I started household monitoring visits, which took place January 8^{th} – 22^{nd}. Field study participants kept filters after the completion of the study.

A variety of household types were chosen for the field study: (1) lower class households living in thatched roofed houses with dirt floors and drinking highly turbid water carried from dug-out dams; (2) lower middle class households living in thatched roofed houses or in concrete houses with tin roofs drinking a variety of highly turbid dam and low turbidity well/municipal sources; and (3) middle class households living in concrete houses and primarily drinking municipal piped water. Previous studies (Green, 2008) found that “roof type” and building material (mud-brick or concrete block) can be used as a surrogate of socioeconomic class. Whereas middle class homes are typically made of concrete block with tin roofs, lower class homes typically are of mud-brick with thatched roofs. This variety of household types allowed for a possible comparison among water types and socioeconomic levels to show how effectively households used the filter and how effectively the filter removed contaminants.

In order to measure how households used the siphon filter, I developed an Effective Use survey sheet specifically for the siphon filter (see *Appendix C: Effective Use Survey*). An Effective Use survey provides a method of monitoring the proper operation of a household water treatment and safe storage (HWTS) technology (Stevenson, 2008)[12]. The Siphon Filter Effective Use sheet allowed the surveyor *to observe* the following aspects of filter use:

(1) Whether the filter was currently being used.

(2) Whether the plastic housing was removed for use. The filter is sold inside a plastic casing that is designed to be removed before use.

(3) Whether the cloth pre-filter was in use.

(4) Whether upper containers were elevated to facilitate fast flow rates, and lower containers were slightly raised from the ground to ensure cleanliness. Study participants were not instructed to raise the lower container, but this practice was presumed to make lower container cleanliness more likely as the container was off the ground.

(5) Whether filters were used in direct sunlight. Sunlight rapidly degrades plastic filter components.

(6) Whether the filter was located out of reach of children and animals, which could tamper with the filter.

(7) Whether the filter and water containers were clean with no visible leaks or cracks.

(8) The water level in the upper container. High water levels cause faster flow rates.

Additionally, the survey included questions regarding aspects of filter use that could not directly be observed; the answers to these questions were *self-reports* by the filter user. These questions investigated:

(9) Whether turbid waters were settled for an hour before filtration to minimize filter clogging.

(10) Whether users remembered how to backwash the filter to prevent premature clogging, and whether users had backwashed the filter since my last visit.

(11) Whether users remembered how to scrub the filter once it clogged.

(12) Whether the scrub pad was producible and clean.

[12] HWTS technologies have been developed in response to the logistic and financial constraints of providing piped or other "improved" supplies to people in developing countries. These technologies are used in the home and can require less capital expenditure than improved source interventions while providing similar health benefits (Stevenson, 2008).

(13) Whether users had cleaned the cloth prefilter since my last visit.

(14) Whether there was a clean cup associated with the filter, to minimize recontamination.

(15) Whether the lower container was cleaned regularly.

At the end of the Effective Use survey I sometimes asked participants additional questions such as what aspects of filter use they found difficult, how many people used the filter and whether it provided enough water for the users. These were informal unstructured ways to learn more about filter use.

To implement the survey I visited each household twice with a Ghanaian guide/translator. These visits were unannounced; at the time of distribution study participants were asked the most convenient times of day for household visits, and were told that the study would take place during the month of January. I interviewed the head of household in charge of the filter and observed the conditions of filter use. When necessary I explained how to use the filter correctly and requested behavior change regarding proper filter use if mistakes were observed. I left a period of approximately one week between visits, as some filter maintenance practices should be done only once every few days, and to best determine patterns of use. The Effective Use survey allowed me to determine how properly the filter was used in each household and to measure patterns regarding various issues with filter use. It also enabled me to be systematic with respect to the twenty-four households surveyed. Finally, the survey allowed an opportunity to train/retrain users in proper use of the siphon filter.

4. Results

For the field study in Ghana, I monitored siphon filters in twenty-four (24) households over a period of three (3) weeks. Microbial water quality tests and Effective Use monitoring were conducted during each household visit. I visited each household twice, yielding forty-eight (48) sets of water quality data (shown in *Appendix D*). Each set consists of household stored water (HSW) and siphon filtered water (SFW) sample data. For the data analysis, each data set is treated individually; the two sets of data obtained for each household is treated as a unique set, rather than averaged. Correlation coefficients were used to describe the relationship of the two data sets.

At MIT during the fall semester I analyzed nine (9) sets of unfiltered source water and siphon filtered water using Charles River (CR) water with clay and dirt from Northern Ghana mixed in, to simulate water found in dams in Ghana.

Diagrams depicting contamination levels exclude sample sets for which both HSW and SFW show undetectable levels of contamination.

4.1 Water Quality

4.1.1 MIT Laboratory Results

4.1.1.1 Total Coliform

Figure 4.1 shows total coliform levels of CR source and siphon filtered water samples.

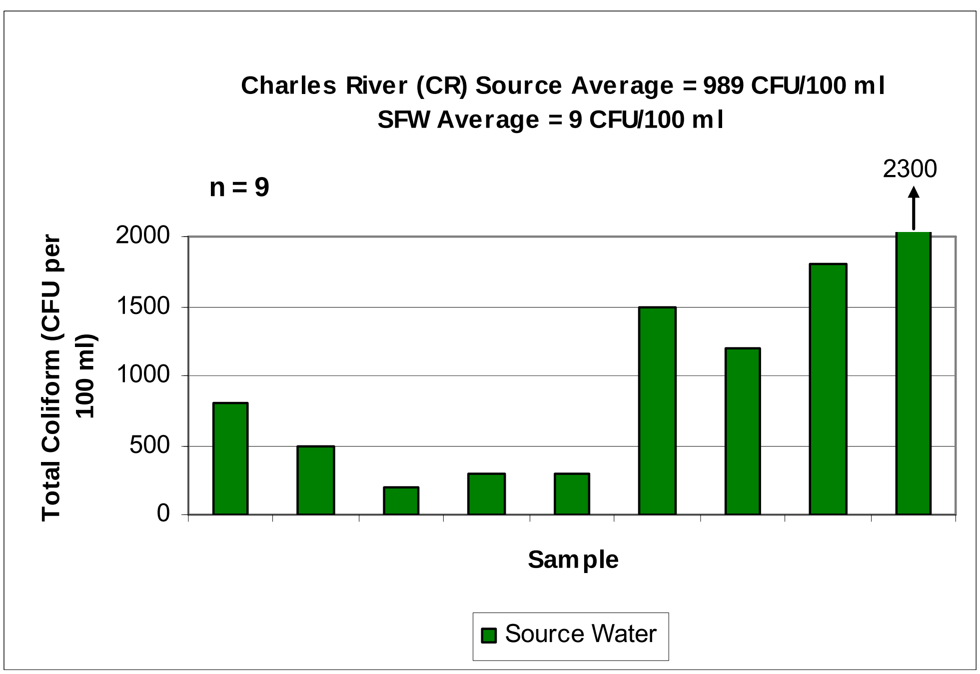


Figure 4.1 Total Coliform Count of CR Source Water and Siphon Filtered Water (MIT Lab Study)

Unfiltered source water samples ranged from 200-2,300 total coliform CFU per 100 ml, reflecting typical high values of total coliform found in surface water in Northern Ghana. All filtered water samples indicated removal of total coliform to below the detection limit of the Colilert® test, which means <10 CFU per 100 ml (these low values are not visible in Figure 4.1). This result was assigned a value of 9 CFU per 100 ml for the purpose of computing percent and log removals. Total coliform percent and log removals are shown in Figures 4.2 and 4.3 respectively.

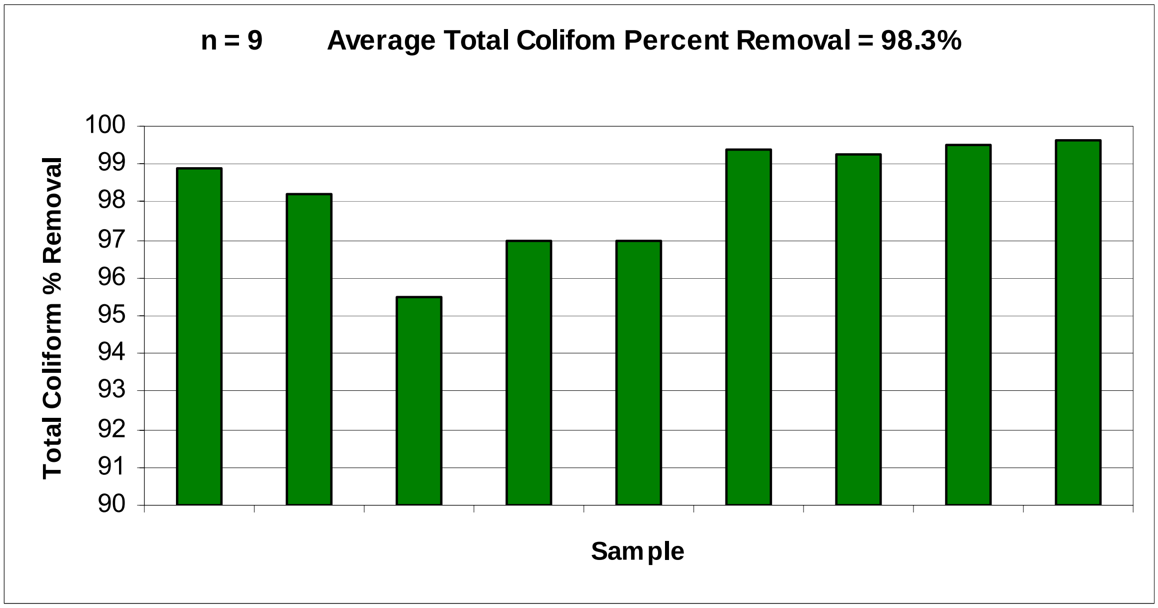


Figure 4.2 Total Coliform Percent Removals (MIT Lab Study)

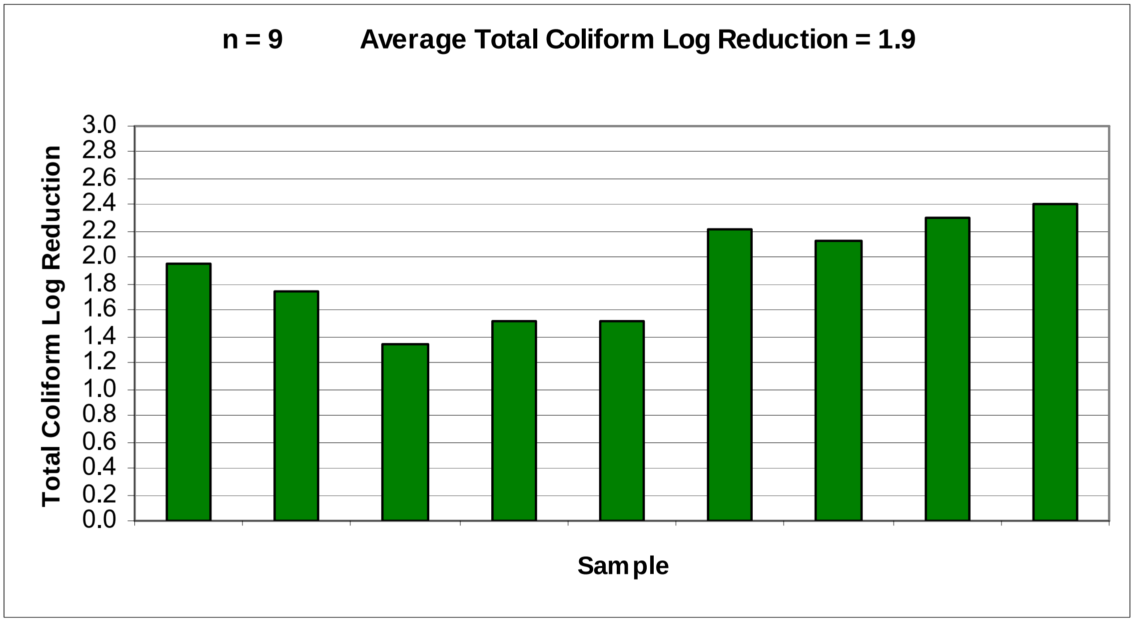


Figure 4.3 Total Coliform Log Reductions (MIT Lab Study)

The filter showed an average removal rate for total coliform of 98.3% for the MIT laboratory tests, with an average log reduction of 1.9. However, the average removal rate for total coliform may have been as high as 99.8% with an average log reduction of 2.9 if optimistic (i.e. non-conservative) values are instead used in calculations.

4.1.1.2 E. coli

All nine (9) source water samples studied at MIT showed *E. coli* contamination. Figure 4.4 shows *E. coli* levels of source and filtered water samples.

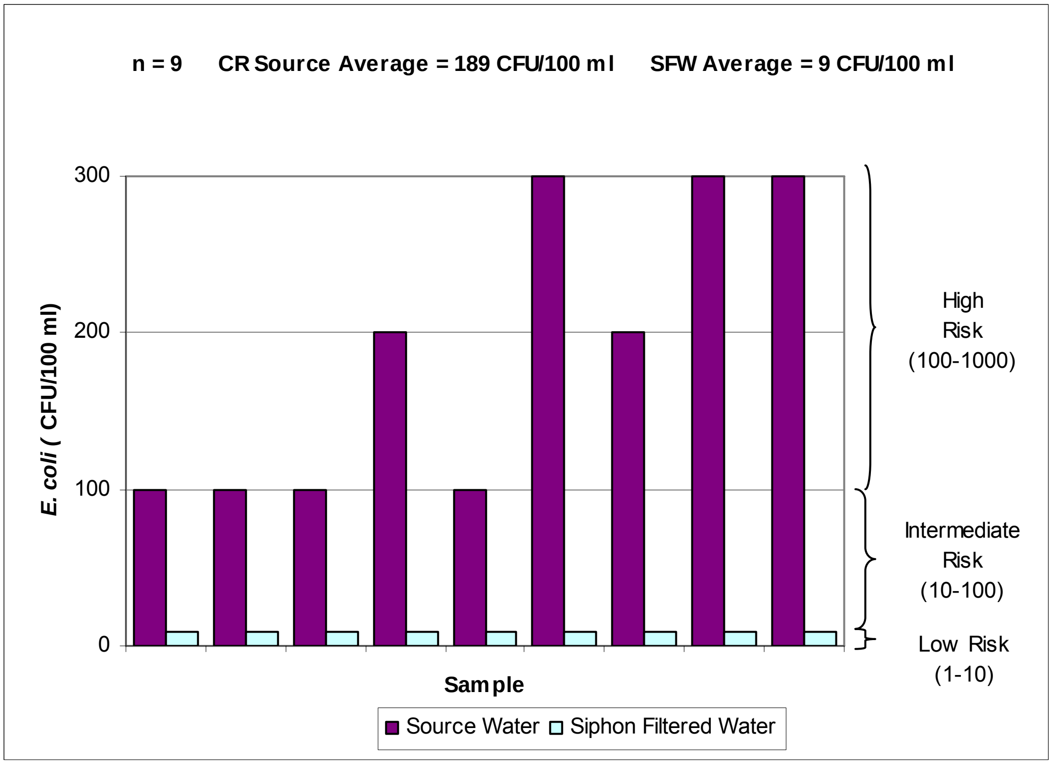


Figure 4.4 *E. coli* Counts of CR Source Water and Siphon Filtered Water (MIT Lab Study)

CR source samples ranged from 99-300 *E. coli* CFU per 100 ml, using the assignment of 99 CFU per 100 ml to samples detectable by the Colilert® test but undetectable by the Petrifilm™ test. (Samples in this category have *E. coli* levels from 10-100 CFU per 100 ml; the Petrifilm™ test has a detection limit of 100 CFU per 100 ml.) The average *E. coli* level of source water was 189 CFU per 100 ml. All corresponding siphon filtered samples showed levels of *E. coli* below the detection limit of the Colilert ® test, corresponding to a low risk due to *E. coli* according to the WHO guidelines (WHO, 2007). Again, a value of 9 *E. coli* CFU per 100 ml was assigned to the negative (undetectable) *E. coli* results for the purpose of calculating percent and log removals. Figures 4.5 and 4.6 show *E. coli* percent and log removals, respectively.

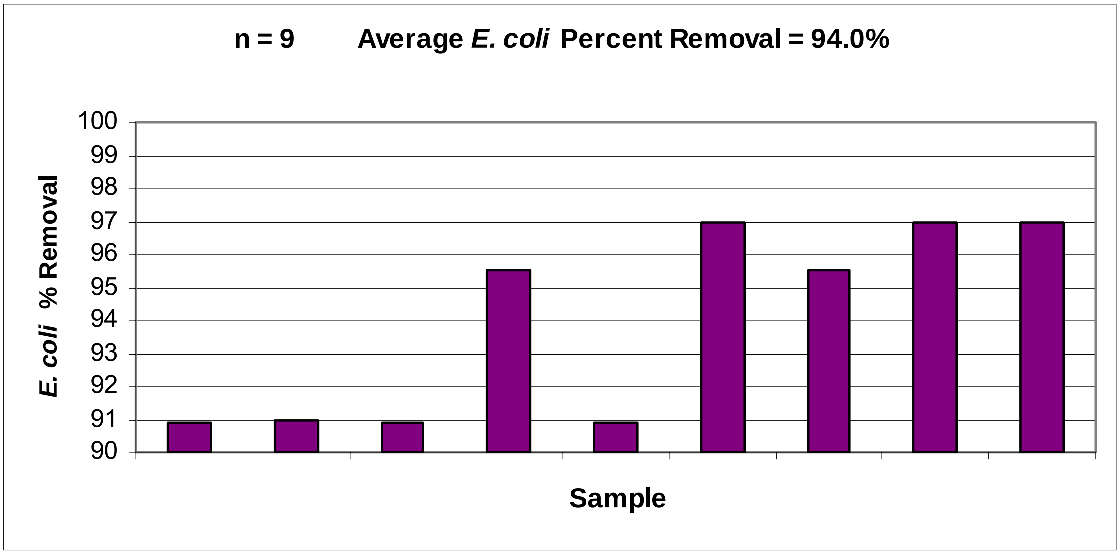


Figure 4.5 ***E. coli*** **Percent Removals (MIT Lab Study)**

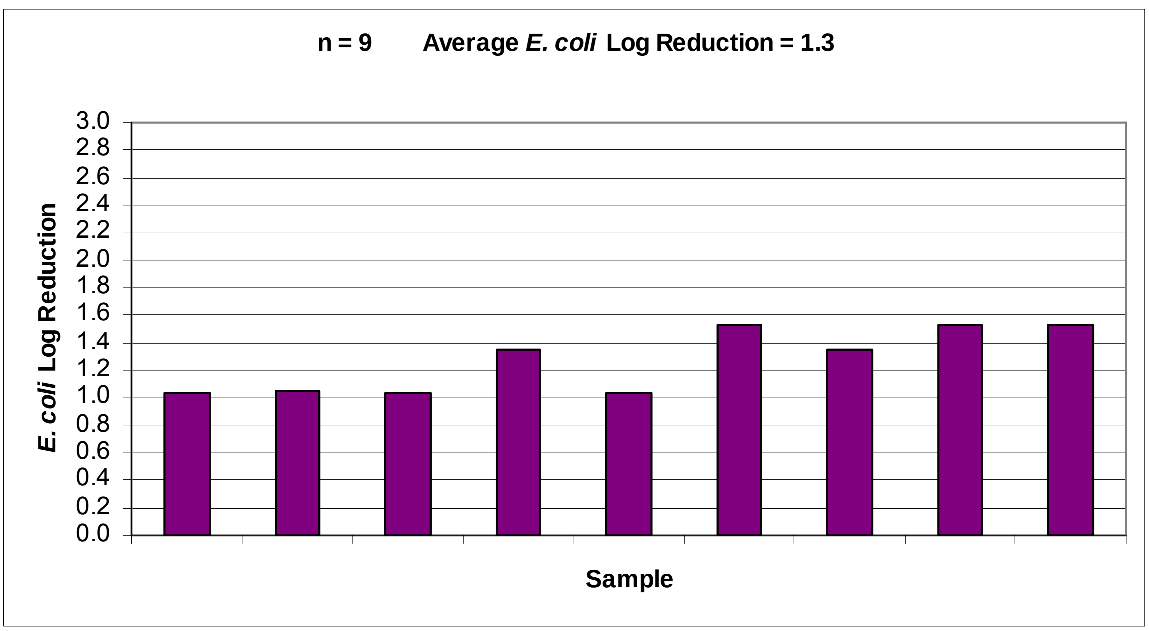


Figure 4.6 ***E. coli*** **Log Reductions (MIT Lab Study)**

The filter showed an average percent removal rate of 94.0% for *E. coli* for MIT laboratory tests, with an average log reduction of 1.3. If non-conservative values are instead used for these calculations, the average percent removal rate for *E. coli* is 96.3% and the average log reduction is 1.9.

4.1.1.3 Turbidity

The "Instructions of Use" sheet for the siphon filter by Basic Water Needs recommends that twenty (20) liters should be filtered and discarded before applying the filter in everyday use (BWN-IU, 2008). The reason for discarding this filtered water before use is to allow ceramic particles to leach from the filter element, which happens when the filter is new. (This practice is advised for aesthetic - taste, color - rather than for health purposes.) Samples from the siphon filter studied at MIT before twenty liters had been filtered showed increased turbidity in filtered water versus source water, indicating ceramic particle leaching. Only samples taken after twenty liters had passed through the filter are included in this analysis. Figure 4.7 shows turbidities of eight (8) of the sample sets studied. Unfiltered source water samples had high turbidities of 101-997 NTU, with a 329 NTU average value. As explained previously, these high turbidities were intentionally created in the lab to simulate potential high turbidities in Ghana. Siphon filtered samples had an average turbidity of 2.2 NTU (these low filtered water values are not visible in Figure 4.7).

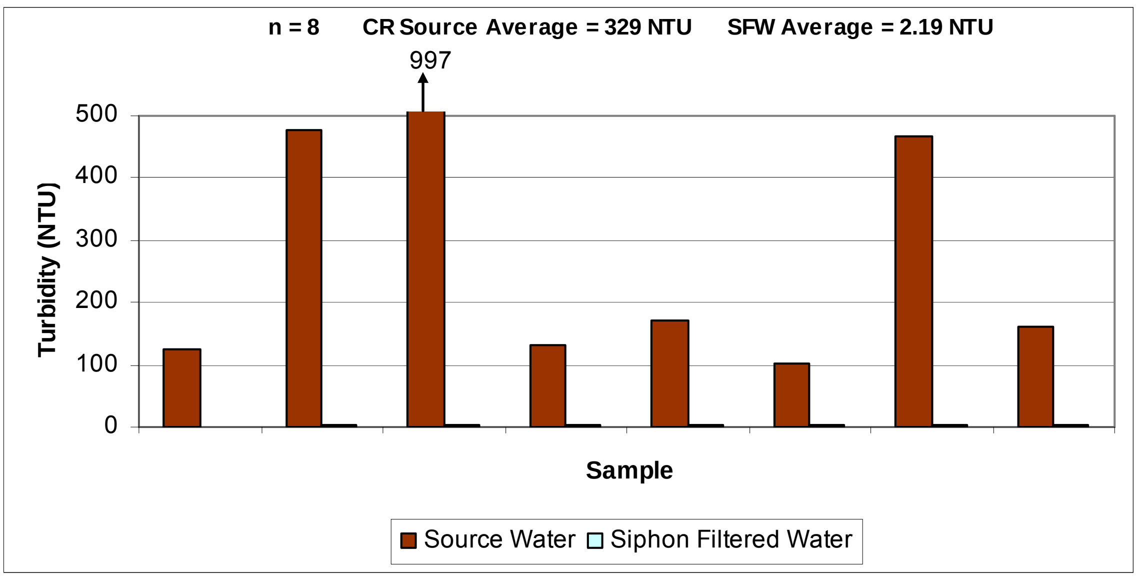


Figure 4.7 Turbidity of CR Source Water and Siphon Filtered Water (MIT Lab Study)

Percent and log removals of the eight sample sets studied are shown in Figures 4.8 and 4.9 respectively.

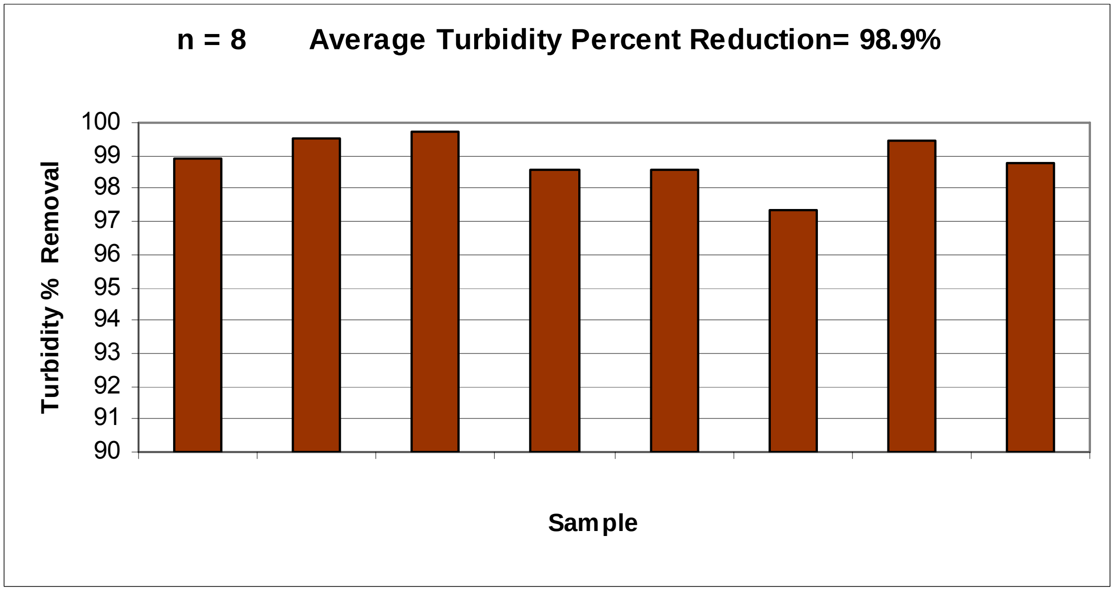


Figure 4.8 Turbidity Percent Removals (MIT Lab Study)

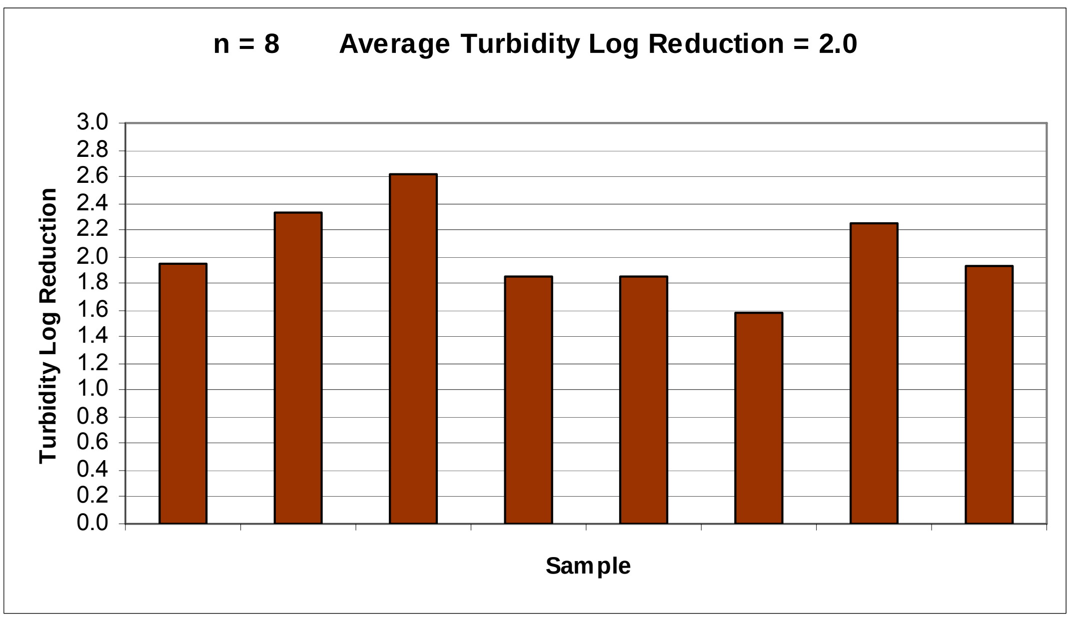


Figure 4.9 Turbidity Log Reductions (MIT Lab Study)

The samples indicated an average turbidity removal rate of roughly 98.9%, and an average log reduction of 2.0 when the ninth sample set was not included in the analysis. The ninth unfiltered sample had relatively low turbidity of 7.92 NTU; the filtered sample had turbidity of 1.7 NTU. If this sample is included in the analysis, then the average turbidity removal is 96.6% and the average log reduction is 1.9.

4.1.1.4 Flow Rate

An average flow rate of roughly 4.0 liters per hour was found at MIT using tap water as the unfiltered water and a distance between the upper and lower water containers of 38 cm. When this distance was increased to 70 cm, which is the distance recommended by the filter manufacturer, an average flow rate of roughly 7.0 liters per hour was measured. The flow rate of 4.0 liters per hour is within the 3-5 liters per hour range reported by the manufacturer (BWN-SFFS, 2008). However, the recommended distance of 70 cm between containers yielded a higher flow rate in the MIT study than reported by the manufacturer. Since flow rates decrease for high turbidity water, perhaps the high flow rates found were due to the low turbidity tap water used. Additionally, of the two (2) siphon filters studied, one filter element was scrubbed immediately prior to the experiment, and the other had only filtered twenty (20) liters of tap water prior to the experiment. These factors may have increased the flow rate.

4.1.2 Ghana Water Quality

4.1.2.1 Source Water Characterization

The twenty-four (24) studied households drank water from four general types of sources: piped supplies, boreholes, wells (both improved and unimproved) and dugout dams. Most households drank primarily from one source, but a few households used more than one water source type. Twenty-five (25) samples were of pipe source water, three (3) were of borehole water, three (3) were of well water and seventeen (17) were of dam water. See Figure 4.10 for a diagram of source water types. Overall, 58% were "improved" sources and 42% were "unimproved" sources (based on an assumption that the three well water sources were all unimproved).

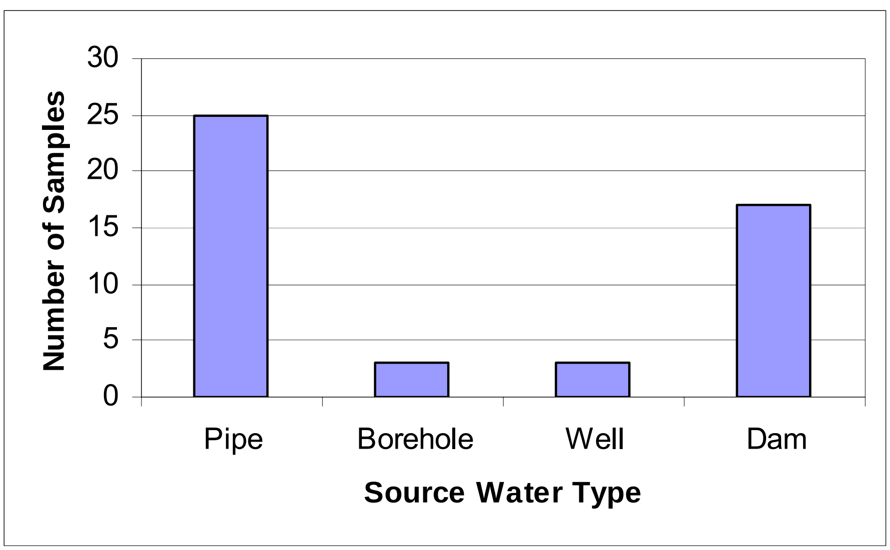


Figure 4.10 Source Water Types

Average turbidities of source water types are shown in Figure 4.11. Turbidities of pipe, borehole, well and dam source waters were on average 6, 20, 16 and 106 NTU, respectively. The correlation coefficient for the two turbidity HSW data sets was 0.84, indicating fairly strong correlation between the two household visits.

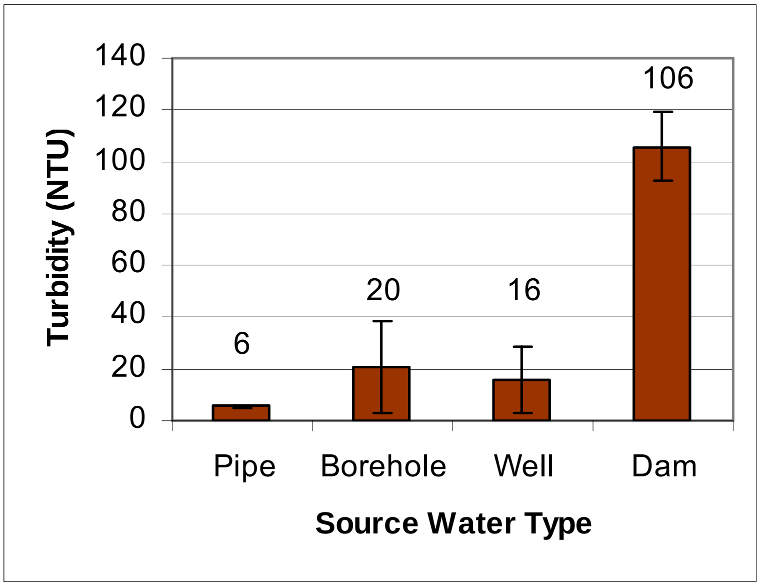


Figure 4.11 Average Turbidities of Source Water Types

Figure 4.12 shows the distribution of HSW samples with detectable and undetectable total coliform levels. Ten (10) of the forty-eight (48) household stored water samples (21%) had no detectable total coliform (i.e. total coliform levels of <10 CFU per 100 ml); these were all originating from piped and borehole water supply sources. Only three (3) of the twenty-four (24) households (13%) showed undetectable levels of total coliform for both HSW samples taken. Of the ten (10) households drinking piped source water for both household visits, only two (2) households (20%) showed undetectable levels of total coliform in both HSW samples. Thirty-eight (38) HSW samples (80%) showed detectable levels of total coliform.

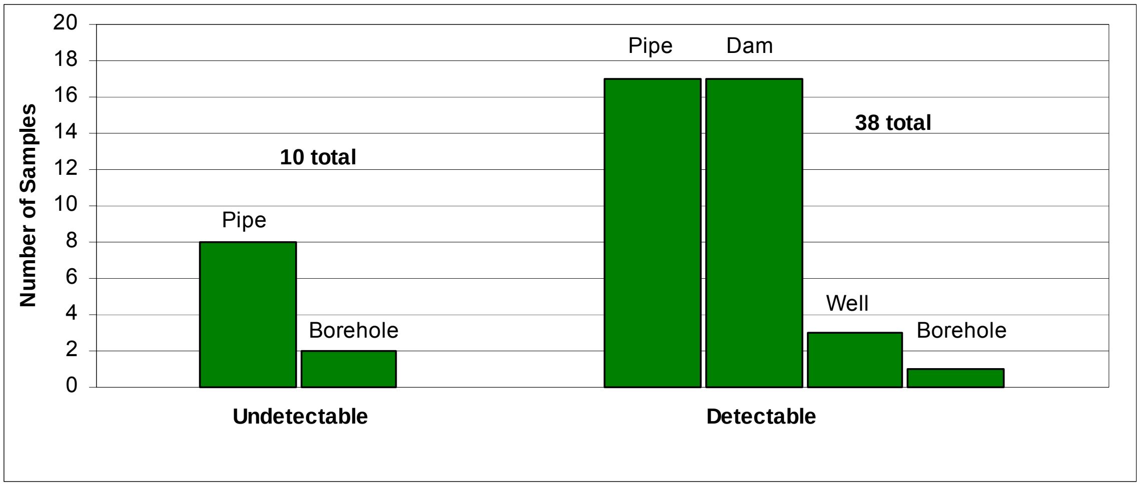


Figure 4.12 Total Coliform Levels of Household Stored Water Samples

Figure 4.13 shows a diagram of average total coliform found in the source water types. Average total coliform CFU per 100 ml of pipe, borehole, well and dam source waters were 2,736, 2,106, 966 and 5,953 respectively. None of the source waters were clean with respect to total coliforms, but the dam water had significantly more total coliform than the other water types. The correlation coefficient for the two total coliform HSW data sets was 0.10, indicating little correlation between the two household visits and suggesting a variety of source types used or variability of the total coliform levels of a single source.

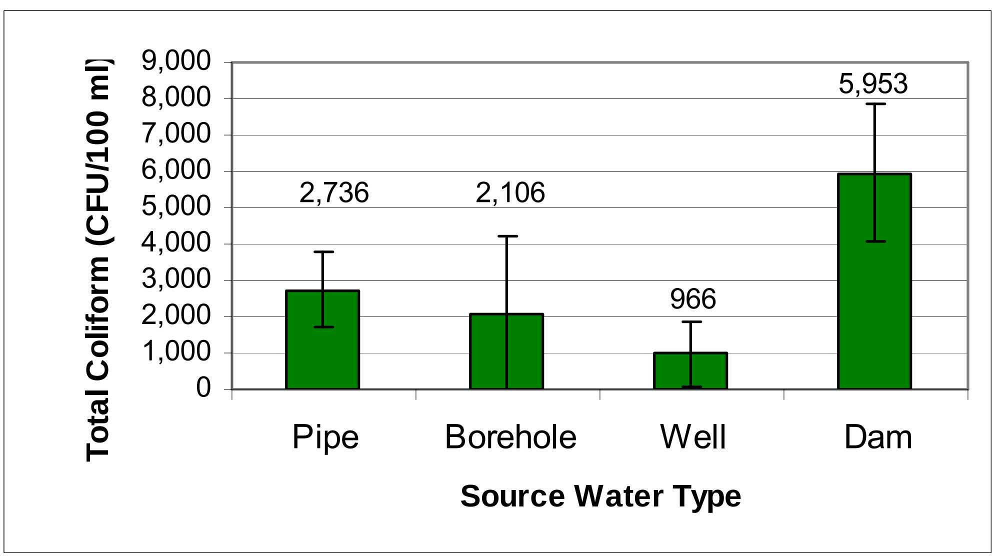


Figure 4.13 Average Total Coliform of Source Water Types

Figure 4.14 shows a diagram of average *E. coli* found in the source water types. Pipe, borehole, well and dam source samples had 166, 173, 39 and 165 *E. coli* CFU/100 ml respectively. Average *E. coli* CFU per 100 ml of source waters were roughly similar among water types, except well water showed lower average amounts of *E. coli*. These values on average correspond to an intermediate risk due to *E. coli* from the well water, and a high risk from the other source types. The correlation coefficient for the two *E. coli* HSW data sets was 0.002, indicating little correlation between the two household visits.

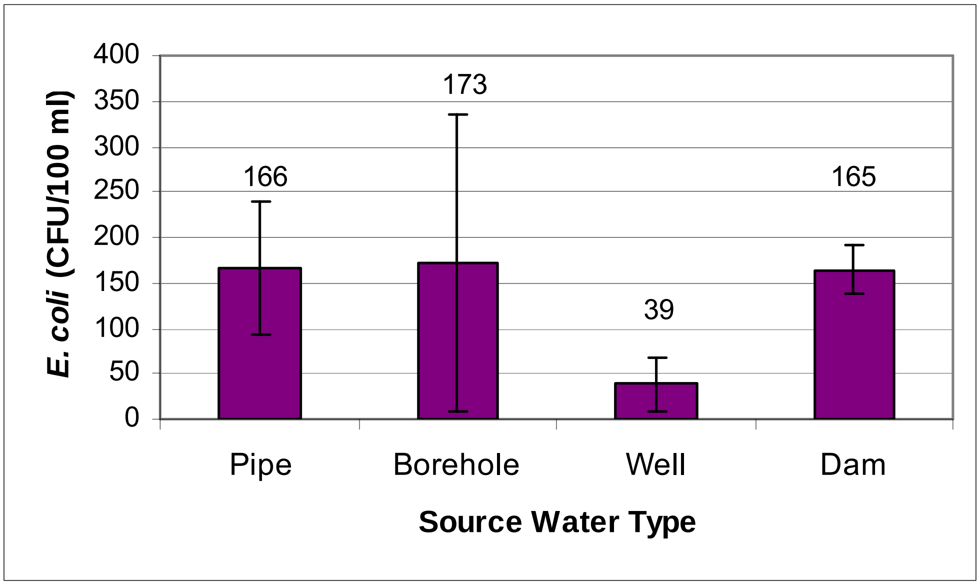


Figure 4.14 Average *E. coli* of Source Water Types

4.1.2.2 Siphon Filter Performance

Water quality data sets consisted of household stored water (HSW) and siphon filtered water (SFW) samples tested for total coliform colony-forming units (CFU) per 100 ml, *E. coli* CFU per 100 ml, and turbidity. Samples were taken from household water storage containers and from the siphon filter tap, in order to avoid measuring possible water storage container recontamination of filtered water. Unfortunately because filter taps often rested inside post-filtered lower water storage containers (typically plastic jerry cans, plastic buckets or metal pails), filtered water samples showing coliform counts may have potentially indicated storage container recontamination rather than poor filter performance. Contamination could also have entered siphon filtered water via dirty hands touching filter taps.

4.1.2.2.1 Total Coliform

Figure 4.15 shows total coliform levels of HSW and SFW, and Figure 4.16 shows these values on a log scale plot.

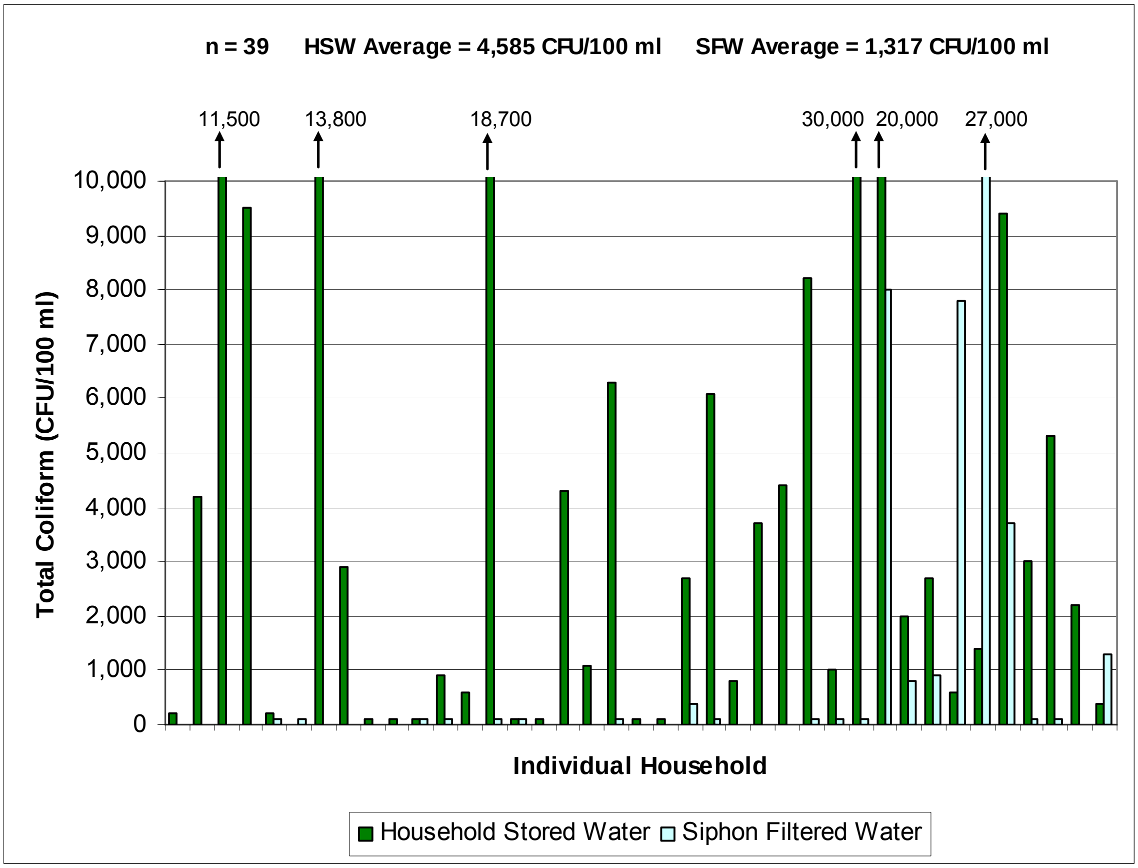


Figure 4.15 Total Coliform Count of Household Stored Water and Siphon Filtered Water

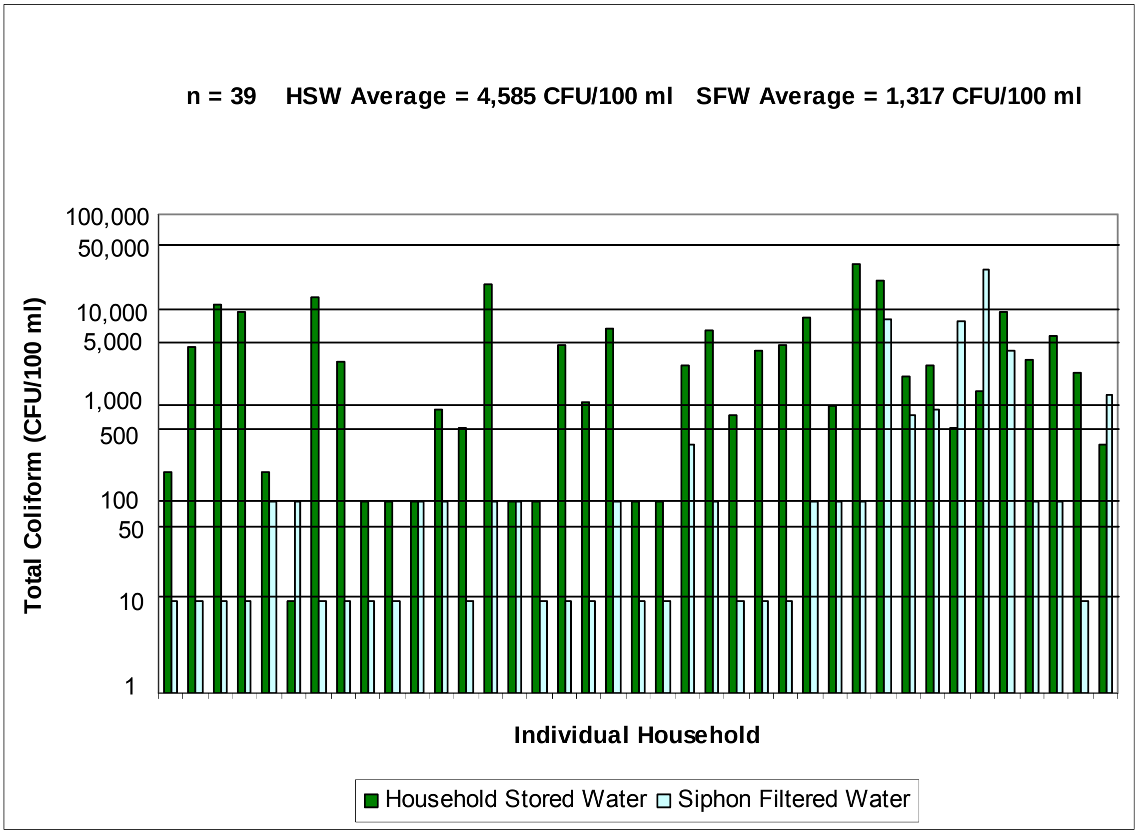


Figure 4.16 Total Coliform Count of HSW and SFW, Log Scale Plot

For the thirty-nine (39) samples showing contamination of either household stored water or siphon filtered water, the average total coliform level of HSW was 4,585 CFU per 100 ml, while the average SFW level was 1,317 CFU per 100 ml. A few filtered water samples showed very high levels of total coliform, which may have been due to filter tap contamination by dirty lower water containers.

Ten (10) HSW (pre-filtration) samples showed no detectable coliform. Of these ten samples, nine (9) corresponding filtered samples showed no detectable coliform as well. (These nine samples are excluded from figures.) The remaining filtered sample showed a total coliform level of 10-100 CFU per 100 ml, as detected by the Colilert® test. This sample suggests potential recontamination by the filter or by filter tap recontamination.

Four (4) additional samples showed more total coliform in siphon filtered than HSW, and one (1) additional sample showed no detectable removal of total coliform. Again, these results may be due to filter tap contamination by dirty storage containers.

Of the thirty-eight (38) HSW samples with detectable levels of total coliform, eighteen (18) of the corresponding filtered water samples (47%) indicated reductions of total coliform to undetectable levels (i.e. below 10 total coliform CFU per 100 ml). The eighteen corresponding HSW samples had total coliform levels ranging from 99-13,800 total coliform CFU per 100 ml, with an average of 3,317 total coliform CFU per 100 ml. Average percent removal of total coliform for these eighteen samples was 96.9%.

Out of the thirty-eight HSW samples that showed detectable levels of total coliform, fifteen (15) filtered water samples (39%) indicated removal of total coliform, but to a level still detectable by the tests used (i.e. above 10 CFU per 100 ml). Of these samples, ten (10) indicated removal of total coliform to 10-99 CFU per 100 ml, and five (5) indicated removal to levels ranging from 400-3,700 CFU per 100 ml. HSW samples of these fifteen sets ranged from 1,000-30,000 CFU per 100 ml. Average percent removal of total coliform for these fifteen samples was 83.4%.

Figures 4.17 and 4.18 show percent and log removals of total coliform respectively.

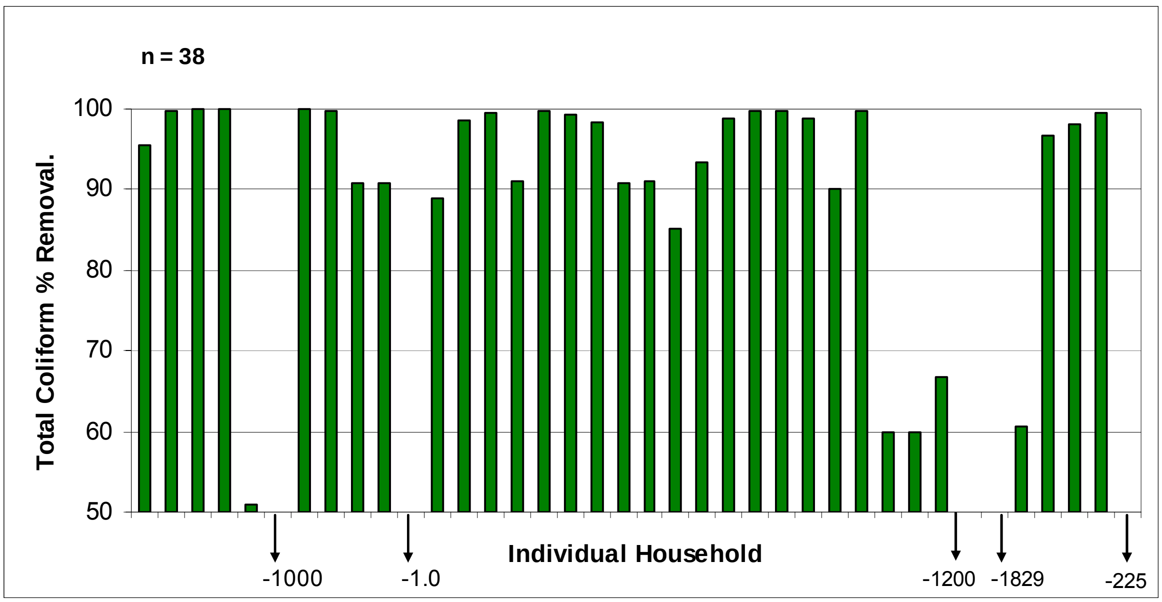


Figure 4.17 Total Coliform Percent Removals

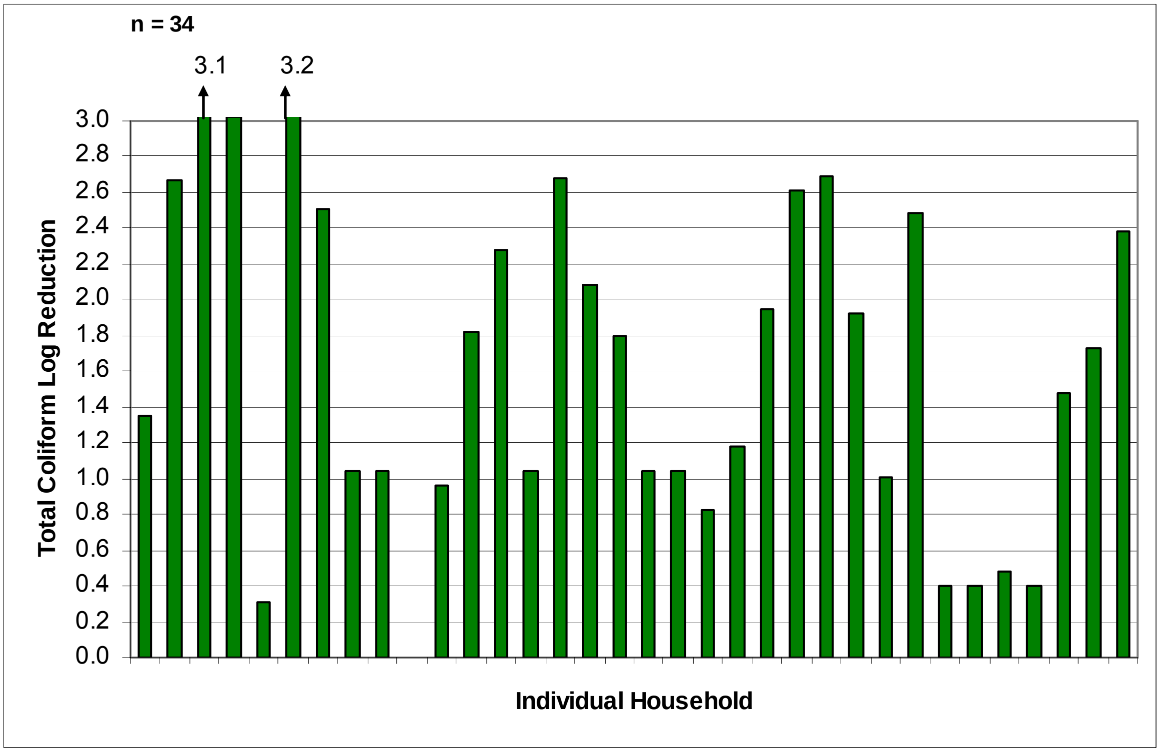


Figure 4.18 Total Coliform Log Reductions

Figure 4.17 includes both positive and negative percent removals of total coliform, whereas Figure 4.18 shows only positive log reductions of total coliform (and one case in which total coliform was not removed or increased). Positive percent reductions of total coliform ranged from 51-99.9% and the average positive percent removal was 90.7%. The average positive total coliform log reduction was 1.7. If non-conservative values are used in calculations, the average positive percent removal of total coliform is 93.7% and the average positive log reduction is 2.4.

The correlation coefficient for total coliform percent removal for the two household visits was 0.87, indicating some correlation between these values for each household.

Figure 4.19 shows average total coliform percent removals for the four source water types. This chart uses only positive percent reductions for samples showing contamination in HSW. (Samples showing recontamination or no removal of total coliform were excluded.) Only one HSW sample of borehole source water type showed contamination, so this value determined the borehole water type average. Total coliform percent removal values were on average higher for piped water than for well or dam water. Although samples showing negative percent removal values were not included in the analysis, recontamination could have lowered the percent removal values of some of the included samples.

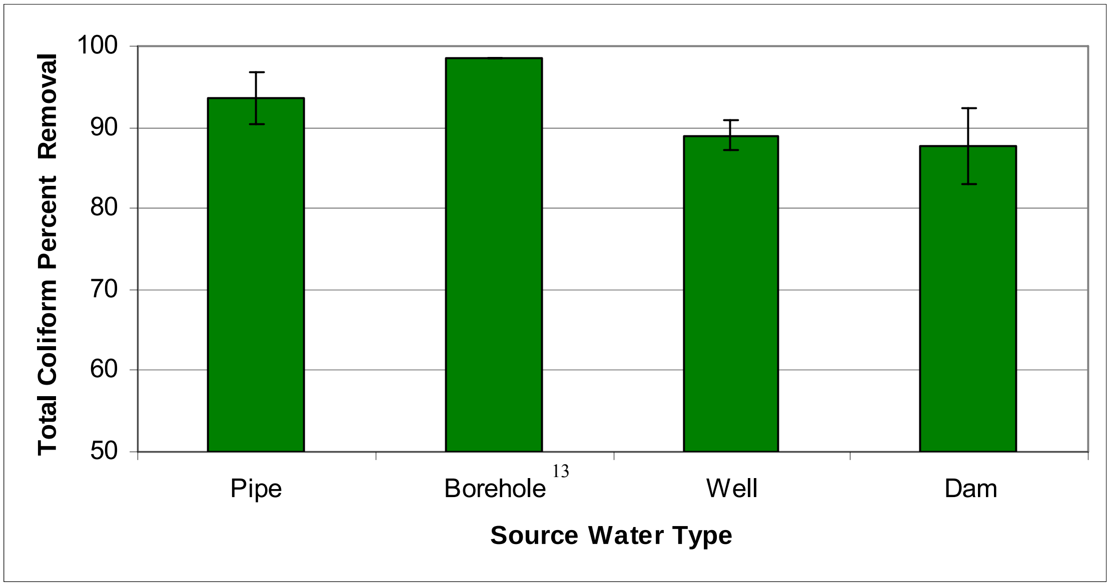


Figure 4.19 Average Positive Total Coliform Percent Removals by Source Water Type[13]

4.1.2.2.2 E. Coli

Figure 4.20 shows *E. coli* contamination of HSW and SFW, and Figure 4.21 shows a summary of *E. coli* removal findings.

[13] One sample only, hence no standard deviation bar.

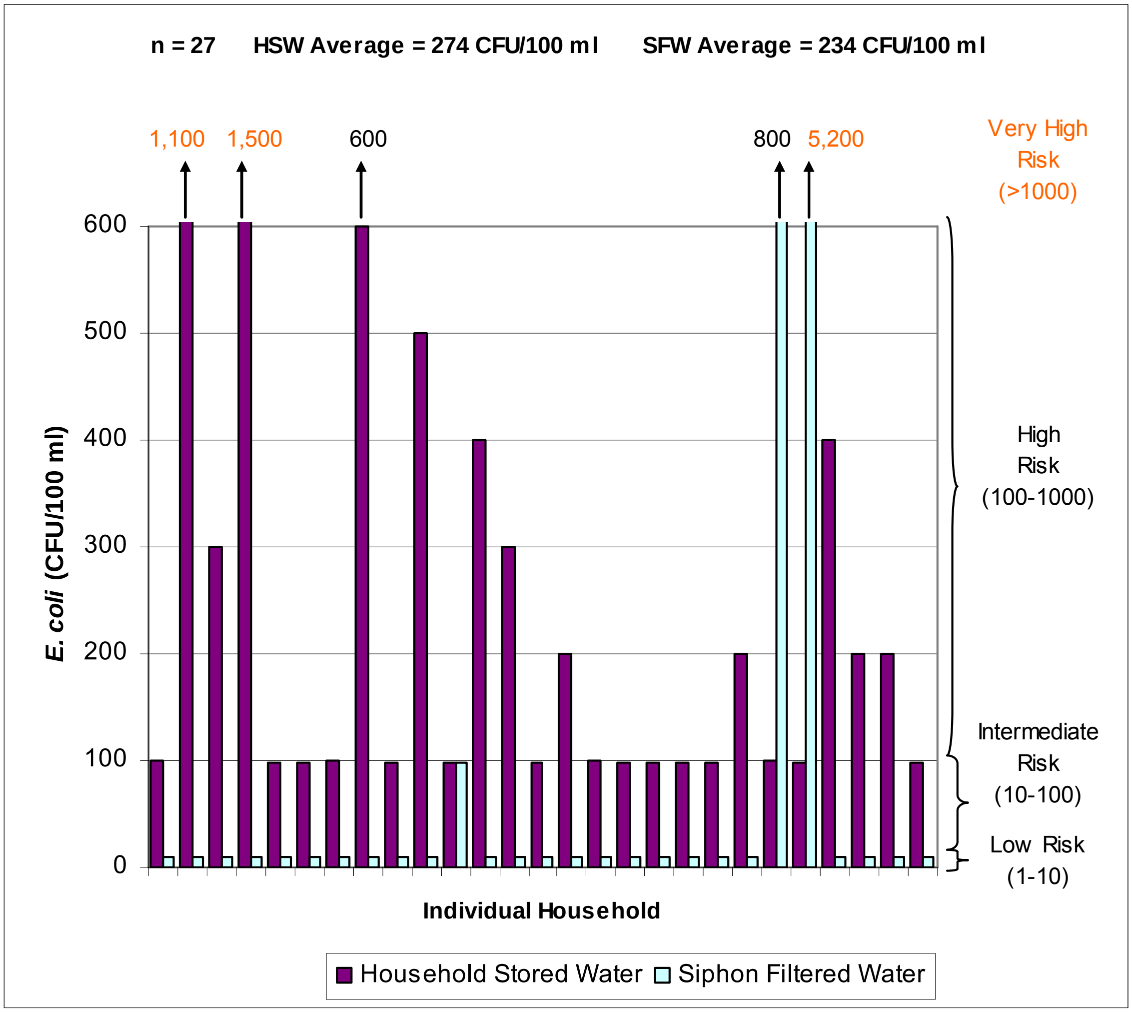


Figure 4.20 *E. coli* Counts of Household Source Water and Siphon Filtered Water

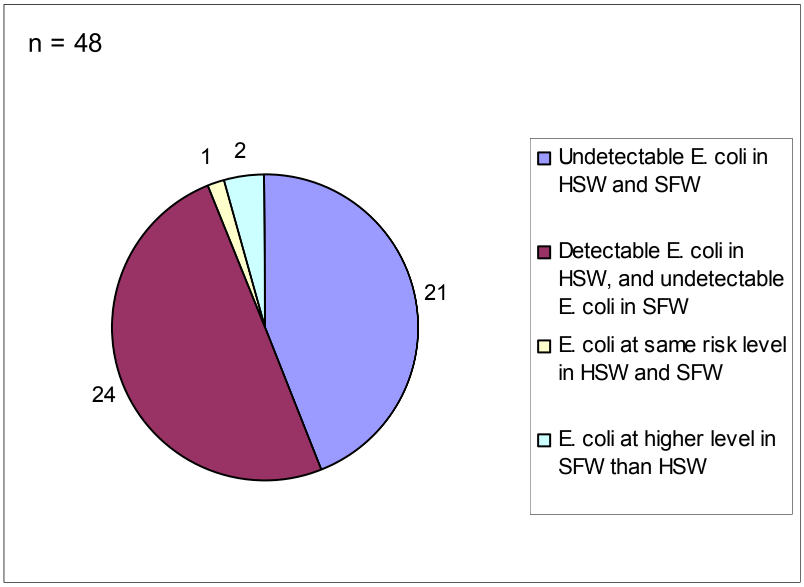


Figure 4.21 Diagram of *E. coli* Removal

Twenty-one (21) HSW samples out of the forty-eight (48) field study samples (44%) showed no detectable *E. coli* contamination levels. No siphon filtered samples corresponding to HSW samples with undetectable *E. coli* levels showed recontamination. Out of the forty-eight field study data sets, twenty-seven (27) HSW samples (56%) showed detectable levels of *E. coli* contamination (i.e. ≥10 CFU per 100 ml). The average level of *E. coli* in HSW for these twenty-seven samples was 274 CFU per 100 ml, and *E. coli* levels ranged from 99-1500 CFU per 100 ml. Of the twenty-seven contaminated HSW samples, all but three (3) corresponding filtered samples showed *E. coli* removal to an undetectable level, corresponding to a low risk level according to the WHO guidelines (WHO, 1997). One (1) HSW sample showing intermediate risk due to *E. coli* showed this same risk level in siphon filtered water. The other two (2) samples were from a single household, and in each case *E. coli* and total coliform counts were higher in siphon filtered water than in household stored water. This indicates possible contamination of the filter tap by dirty hands or by a dirty water storage container. One of these filtered samples indicated high risk from *E. coli* of filtered water and the other indicated very high risk; the corresponding HSW samples showed high and intermediate risks respectively.

Figures 4.22 and 4.23 show percent and log removals of *E. coli* respectively.

Figure 4.22 *E. coli* Percent Removals

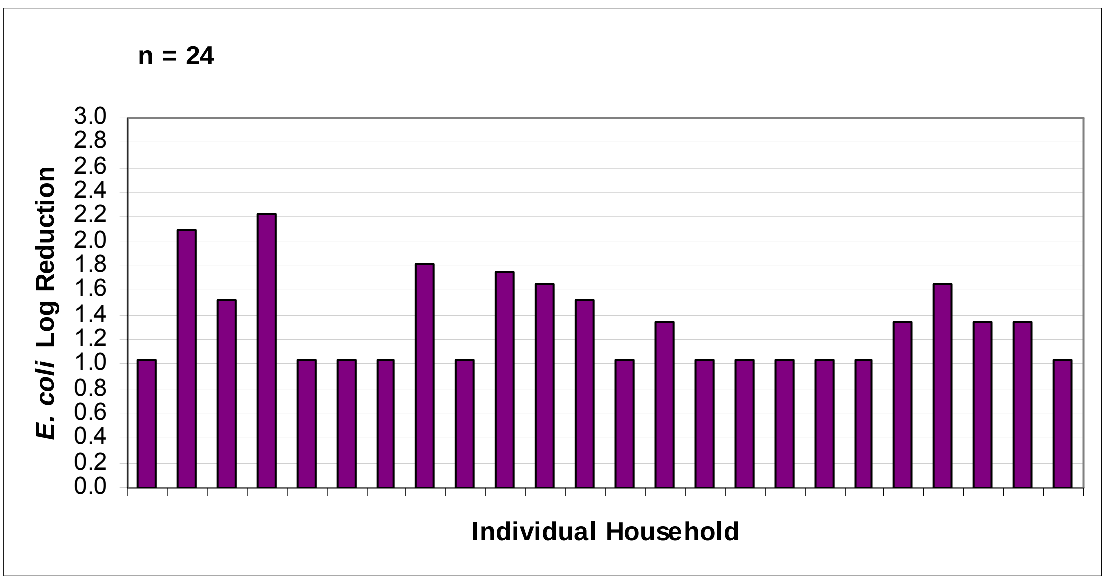


Figure 4.23 *E. coli* Log Reductions

Figure 4.22 shows both positive and negative percent reductions, while Figure 4.23 shows only positive log reductions. Because of the two samples in which *E. coli* concentrations were higher in filtered than in HSW, and the one sample in which no *E. coli* removal occurred, the average percent removal for *E. coli* was -133%. However, omitting these three samples generates an average percent removal for *E. coli* of 94.1%, and an average log reduction of 1.3. Additionally, if non-conservative values are used in calculations, the average percent removal for *E. coli* is 96.0% and the average log reduction is 1.9. The highest *E. coli* concentration found in unfiltered water was 1,500 CFU per 100 ml, and the filter removed *E. coli* to an undetectable level (<10 CFU per 100 ml) in this case. In all but the three cases discussed above, the siphon filter met WHO's suggested guideline value of undetectable *E. coli* in drinking water.

The correlation coefficient for *E. coli* percent removal for the two household visits was 0.9999, indicating strong correlation between these values for each household.

4.1.2.2.3 Turbidity

Figure 4.24 shows turbidity of HSW and SFW. A dashed line separates sample sets of households drinking dam water from those of households drinking from other sources, in order to illustrate the relatively high turbidities of dam water.

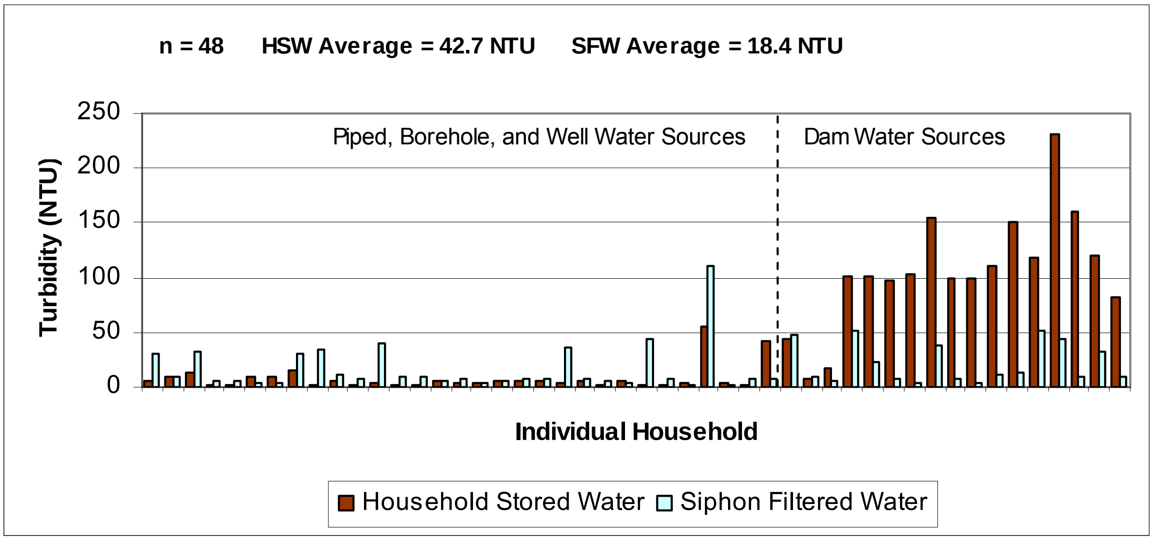


Figure 4.24 Turbidity of Household Stored Water and Siphon Filtered Water

Turbidities of dam HSW were typically significantly higher than turbidities of pipe, borehole or well source type HSW. Household stored dam water was an average of 106 NTU, whereas other sources were an average of 8.0 NTU. Fifteen (15) of seventeen (17) dam water samples indicated lower turbidities of SFW versus HSW. However, most pipe, borehole and well water samples showed higher turbidity in filtered than HSW samples. This is likely due to ceramic particle leaching of the filter element, since households had used the filter a short period of time. I did not advise study participants to discard twenty liters before drinking filtered water (as the manufacturer advises) because I did not want to encourage households to waste water for aesthetic purposes. Highly turbid HSW samples may have showed typically lower turbidities after filtration because ceramic leaching effects were mild in comparison to removal of high initial turbidities by the filter.

Figure 4.25 shows turbidity percent removals, and Figure 4.26 shows turbidity log reductions of each household.

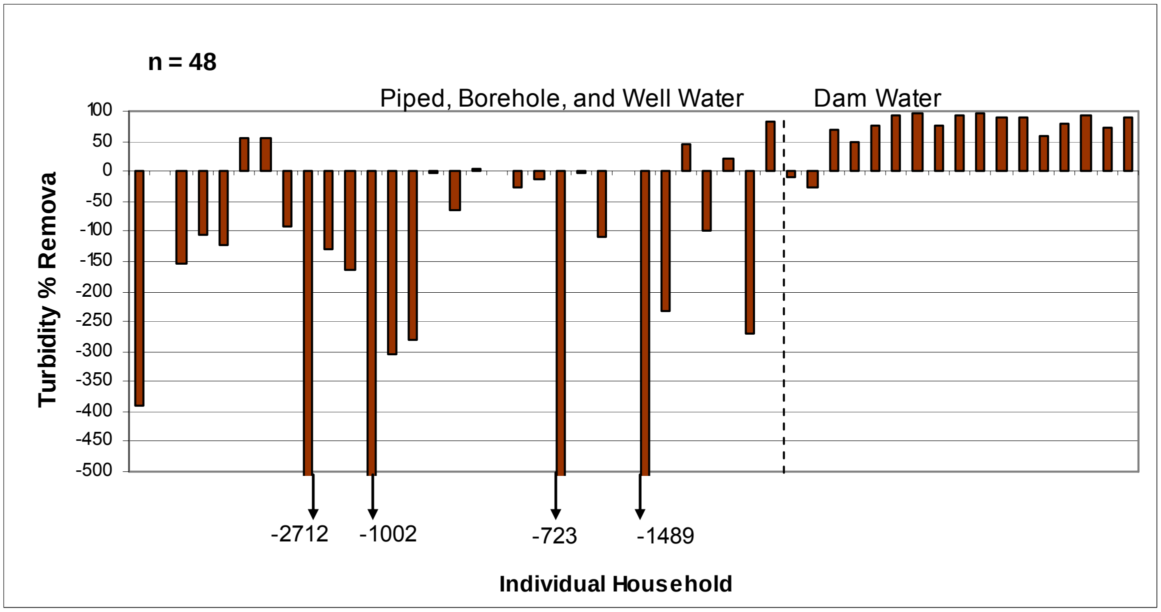


Figure 4.25 Turbidity Percent Removals

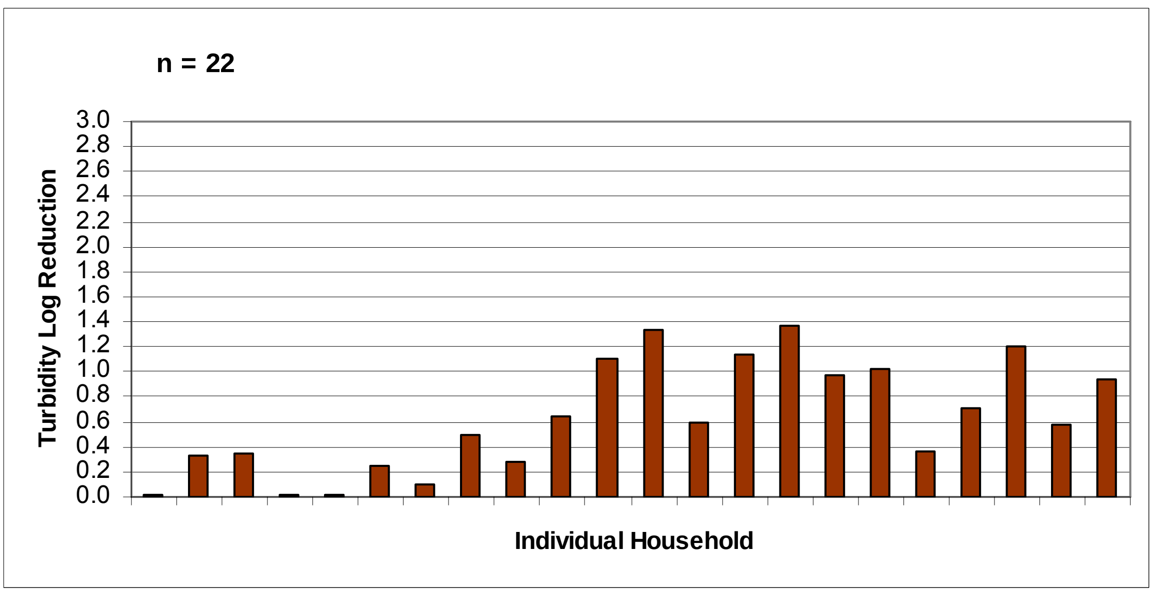


Figure 4.26 Turbidity Log Reductions

Most of the piped, borehole and well source type samples showed negative percent removal for turbidity, probably because of ceramic particle leaching. Dam water samples typically showed positive percent removals, perhaps because although ceramic leaching may have occurred, HSW samples had high enough turbidities to receive overall removal from the siphon filter, as discussed above. For the fifteen (15) sample sets that showed turbidity removal for dam water, the average turbidity removal rate was 81.2%, and the average log reduction was 0.85. As all filters likely underwent ceramic particle leaching during the field study, turbidity removal of the filters may improve in the future.

The correlation coefficient for turbidity percent removal for the two household visits was 0.95, indicating strong correlation between these values for each household.

4.2 Effective Use Survey

Twenty-four (24) households were monitored using the Effective Use survey to determine to what degree the filters were used properly. The Effective Use survey instrument has been described in section *3.2* and is provided in *Appendix C*. Seventeen elements were determined to characterize effective use of the filter; these are discussed below.

4.2.1 Consistency of Filter Use during Study

Filter use was inferred by whether the siphon filter was in an upper water container at the time of my arrival for an unannounced household visit. Ten (10) of the twenty-four (24) households (42%) were using siphon filters at the time I arrived to both household visits (Figure 4.27).

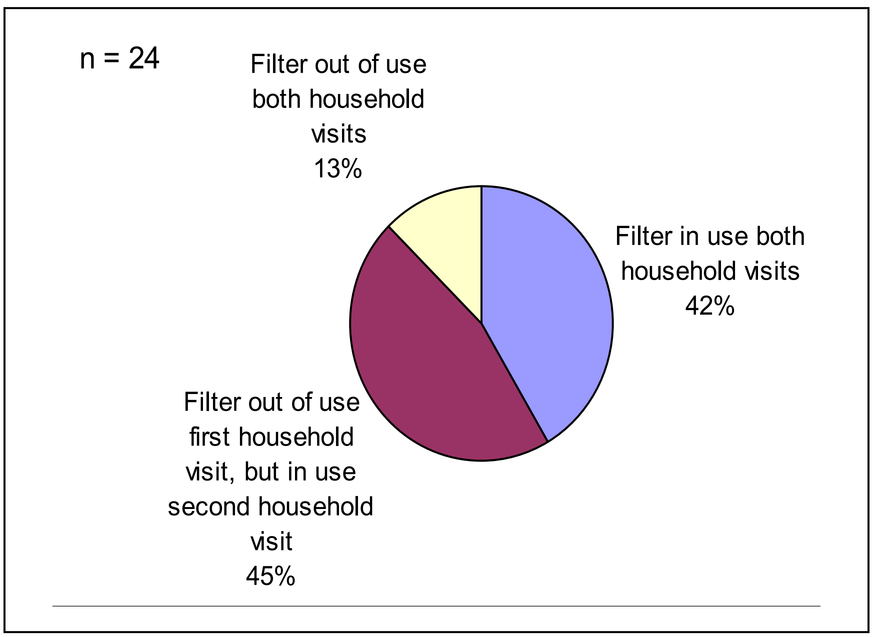


Figure 4.27 Households Using Siphon Filter during Study

Eleven (11) households (45%) were not using the filter at the time of the first household visit, but were using the filter at the time of the second household visit. Three (3) of these households did not use the filter at the time of the first visit because children tampering with the filter led study participants to remove the filter. One study participant stated that she had stored the siphon filter because kids were tampering with it, but also because she currently had enough water, and noted that she had been using the filter regularly. One household did not use the filter before the first household visit because the PHW distributors explained the filter to the elderly mother of the study participant, and the mother did not understand the filter well enough to later explain its use to the study participant. Another household's landlord claimed the filter as his own and took it to his house, preventing the study participant from using a filter until it was replaced after the first household visit. Other reasons for disuse included removing the filter because large numbers of people gathered in a veranda where the filter was used, and filter clogging due to highly turbid waters (backwashing and scrubbing was not well-understood to this study participant at the time of the first household visit). Additional reasons for disuse may have included lack of understanding about the filter, as most participants used the filter at the time of the second household visit.

Three (3) households (13%) were not using the filter at the time of either household visit. One of these households did not use the filter at the time of the first household visit although the household drank dam water (disuse was likely related to lack of understanding about the filter and about water-related hygiene), and did not use the filter at the time of the second visit because the participant perceived a new municipal piped water supply did not require filtration. A second household did not use the siphon filter because of the "bitter" taste of the water. I advised the participant to filter twenty liters of water through the filter and explained that this would remove the ceramic particles likely causing the bitter taste, but the participant did not take this advice by the time of the second visit and the filter was still in disuse. The third household was not using the filter at the time of the first visit for unclear reasons, and had not returned the filter to use after storing it when leaving on a trip sometime before the second household visit. This household had used the filter at least once during the study, as evidenced by the highly scrubbed filter element.

4.2.2 Plastic Housing Removal for Filter Use

The siphon filter is sold in a plastic jar-like housing to prevent ceramic element breakage during transport. This housing is designed to be removed before filter use. When the filter is used with the housing on, a small hole in the housing, which is likely intended to prevent condensation during storage, does allow water to flow through the casing to the ceramic element, but flow rates are minimal. Of the ten (10) households that used the filter at the time of the first visit, only one (1) household removed the plastic housing before use (Figure 4.28).

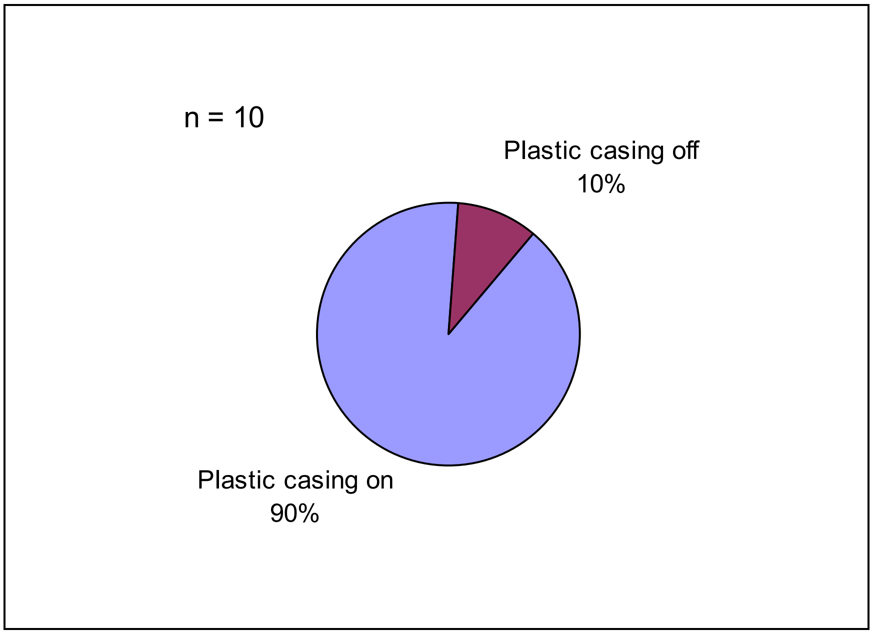


Figure 4.28 Plastic Housing Removal for Households Using Filter at First Household Visit

Most of the households initially used the filter with the housing attached, due to a lack of communication between myself and the filter distributors about an issue that seemed obvious to the author but that was not obvious to the PHW staff that disseminated the filter. The issue was easily remedied by asking households to remove the housing before filter use, which all households remembered on my subsequent visit.

4.2.3 Cloth Pre-filter Use

Only one (1) household used the siphon filter without the cloth pre-filter over the ceramic element. After an explanation during the first household visit, this household used the filter with the pre-filter at the time of the second visit.

4.2.4 Distance between Upper and Lower Containers

In order for water to flow through the siphon filter, the tap must be lower than the ceramic element. Flow rates are fastest when the distance between tap and ceramic element are greatest (up to a distance limited by the 140 cm length of the tubing[14]). The filter manufacturer recommends a distance of 70 cm between the upper and lower containers, corresponding to the upper container raised to roughly table height when the lower container is near ground level.

Only eight (8) out of twenty-four households (33%) had their filter element raised to table height (either due to elevated or very tall upper container) (Figure 4.29). Instead what was observed was that households often used large clay water storage vessels as their upper containers, and these containers could not easily be elevated due to weight, size and fragility (Figure 4.30). Additionally, many households (especially rural households)

[14] This measurement includes the length of the bulb and tap.

lacked sufficient materials to elevate upper containers. Upper containers resting on the ground resulted in limited distance between upper container water level and tap. Based on my observation it appeared that households using high turbidity water usually showed relatively slow flow rates; in some cases this may have been due to a combination of particle clogging and short distance between tap and upper container water level. Households showing the fastest flow rates had large distances between upper and lower containers, as one would expect due to the greater pressure head.

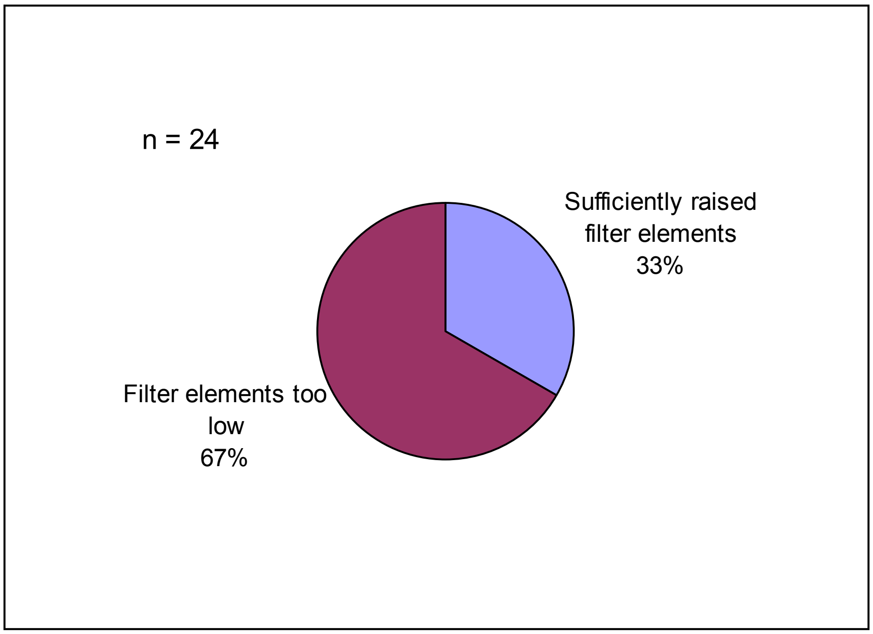


Figure 4.29 Heights of Filter Elements in Upper Water Containers

Figure 4.30 Woman with large ceramic pot used as upper container for siphon filter

Although survey participants were not asked to raise lower containers slightly off the ground (for example by placing their lower container on a low stool), this practice was presumed to make the lower container cleanliness more likely. Only three (3) study participants raised their lower containers (no participants raised lower containers so high that upper and lower containers were too close to achieve a reasonable flow rate).

4.2.5 Use in Direct Sun

Ten (10) of the twenty-four households (42%) used the filter outdoors in direct sunlight, as shown in Figures 4.30 and 4.31. Use in direct sun is not recommended (as per the *Instructions for Use* sheet, shown in Figure 2.9) as sunlight causes rapid degradation of the plastic parts of the filter. However, the manufacturer is developing its third version of the filter with plastics parts that are reported to last at least five (5) years in direct sunlight.

The PHW staff who distributed the filter did not state to study participants to use the filter out of direct sunlight; this was an oversight.

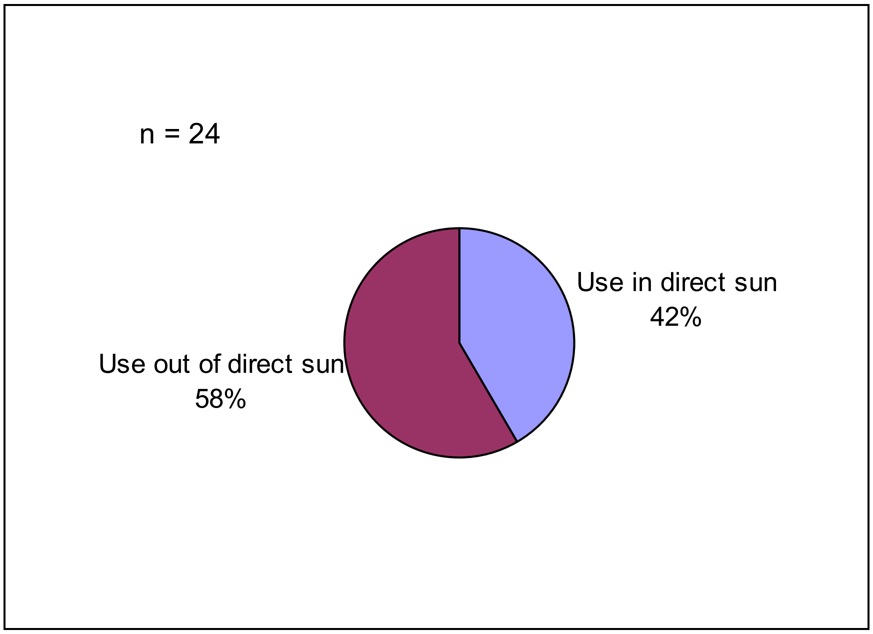


Figure 4.31 Percentages of Household Filter Use in Direct Sun

4.2.6 Child and Animal Access

Eighteen (18) of twenty-four households (75%) used the filter within reach of children or animals (Figure 4.32). Several households reported problems with children tampering with the filter, but many household heads resolved this issue by putting the filter away when they could not watch the filter. The obvious drawback of doing so is that the filtered water might not be available as readily as one might wish.

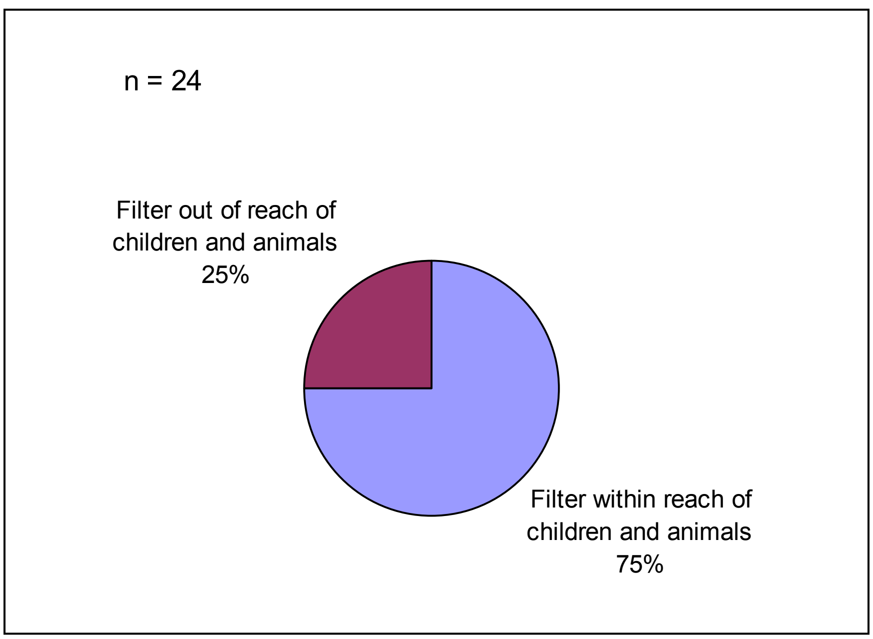


Figure 4.32 Child and Animal Access to Filter

4.2.7 Lower Water Container Cleanliness

In order to roughly gauge lower container cleanliness, I visually assessed the containers. Almost all these containers (92%) appeared clean. However, microbial contamination of the lower container was not measured and could not be assured. Recontamination of filtered water by these containers was possible. Filtered water samples were taken directly from filter taps to measure filter effectiveness rather than storage container cleanliness; however, since many filter taps rested on lower container surfaces, recontamination of filtered water samples was possible. Recontamination of filtered water samples likely occurred in a few water quality tests, in which filtered samples showed higher levels of microbial contamination than unfiltered samples; see *4.1.2.2.1 Total Coliform* section for a more detailed discussion and analysis.

No cracks or leaks were found in any lower or upper water containers.

4.2.8 Upper Container Water Level

All upper containers were filled with greater than two (2) liters of water, which was judged to be a rough minimum amount for sufficient flow rate. High upper container water levels can create high levels of pressure that force water through the filter element, and can help increase the distance between the upper container water level and the filter tap, each resulting in high flow rates. As upper container water levels drop, flow rates generally decrease as well. Upper container water levels were always found to be sufficient in this study.

4.2.9 Settling Turbid Source Water

For households using turbid water sources, settling water before filtration reduces the needed frequency of scrubbing and therefore lengthens the life of the filter. Eleven (11) total households, or 46% of the twenty-four (24) households surveyed, drank from turbid sources at the time of at least one household visit; and eight (8) households, or 33% of the 24 households surveyed, drank from turbid sources at the time of both household visits. On my first visit to households using turbid water sources (i.e. dam sources) for drinking, I suggested allowing water to settle for one (1) hour before pouring only the cleaner top portion into the upper container for filtering. I explained that the filter would need to be cleaned less often if less dirt were in the upper container's water, and how scrubbing eventually made the filter too thin to work well. I asked these households to settle their source water to extend the lives of their filters, and not to have to scrub them as often. Of the six (6) households using dam water throughout the study, only two (2) households (33%) adopted the practice of settling water for an hour before filtering. Additionally, two (2) households drinking dam water at the time of the first household visit and highly turbid borehole and well source water (>40 NTU), respectively, at the time of the second household visit, did not settle water before filtering. Including these households in the analysis indicates that only 25% of the eight (8) total households drinking from highly turbid water sources settled water before filtration (Figure 4.33). This indicates that settling of source water before filtration may not be readily implemented.

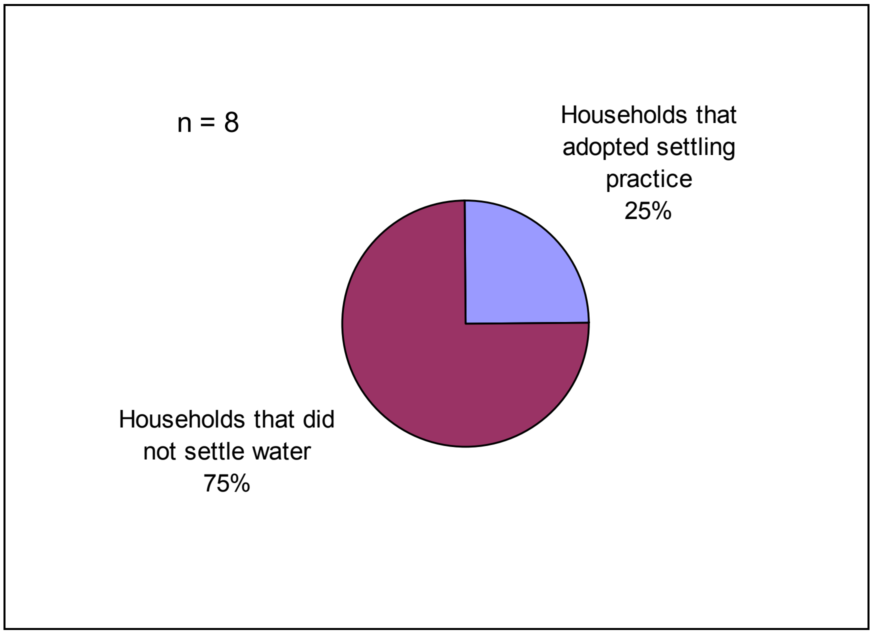


Figure 4.33 Settling Practices of Households Using Turbid Water

4.2.10 Backwashing the Filter

Backwashing is a method of cleaning the ceramic element that lengthens the siphon filter's life by reducing the frequency of necessary scrubbing. The manufacturer suggests backwashing the filter once a day. This practice is more important with turbid waters, as clogging happens more frequently. On my first visit to households I explained how to backwash, as no households remembered the PHW distributors' explanation (assuming backwashing had been explained to each household as reported by the distributors). When I returned roughly a week later, only six (6) of the twenty-four (24) households (25%) remembered when and how to backwash, and only two (2) households (8%) had backwashed since my last visit (Figure 4.34). Since backwashing was not commonly practiced, this implies that scrubbing was the primary cleaning mechanism for the ceramic element for most households.

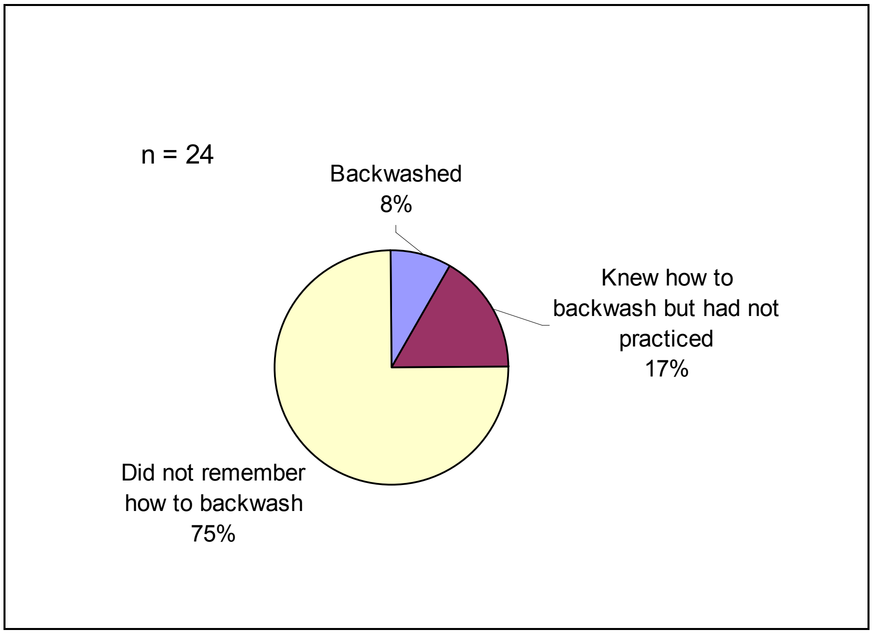


Figure 4.34 Percentages of Households with Backwashing Knowledge and Practice

Furthermore, only four (4) of the eleven (11) households (36%) drinking turbid water at the time of at least one household visit remembered when and how to backwash. This is especially significant because filter use with turbid water requires regular cleaning, and if backwashing is not performed, then frequent scrubbing is necessary. Figure 4.35 shows backwashing knowledge of households drinking turbid water.

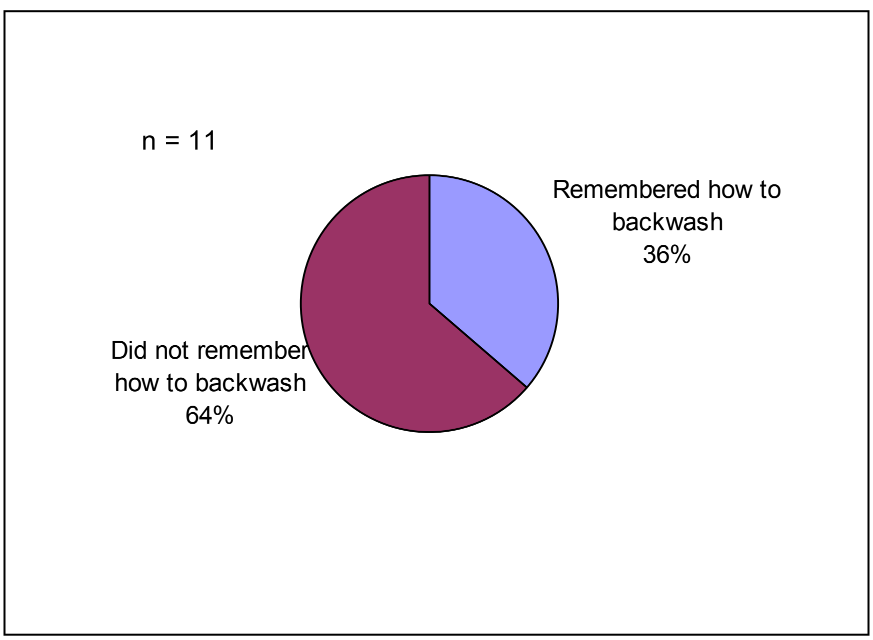


Figure 4.35 Percentages of Backwashing Knowledge among Households with Turbid Water

4.2.11 Scrubbing the Filter

Study participants more easily remembered that one can scrub the filter to restore the filter's flow rate. In fact, eight (8) households (33%) had scrubbed the filter during the study; in all cases these households had scrubbed before backwashing. All but one of these households used dam source water (typically highly turbid; 16.7-155 NTU range) at some point during the study (the remaining household used a piped supply), and five (5) of these households used highly turbid water (dam, well or borehole source type; 41.5-155 NTU range) at the time of both household visits. The highly turbid water may have clogged these filter elements more than elements filtering low-turbidity source water. Two (2) participants had clearly removed more ceramic material than necessary by excessive scrubbing. Only five (5) study participants (21%) understood the correct procedures for both backwashing and scrubbing, including that one scrubs only when backwashing fails to restore the flow rate.

4.2.12 Scrub Pad

When asked to produce the scrub pad included with the siphon filter, twenty (20) households (83%) were able to find the scrub pad (Figure 4.36). The other four (4) households had lost the scrub pad. I replaced lost scrub pads when possible, and directed the other households to purchase rough dish-washing sponges as replacement scrub pads. All scrub pads were visually clean. (While from a hygienic point of view scrub pad cleanliness is preferred, it is not essential for filter performance; however, scrub pads are presumed to remove ceramic material better when clean.)

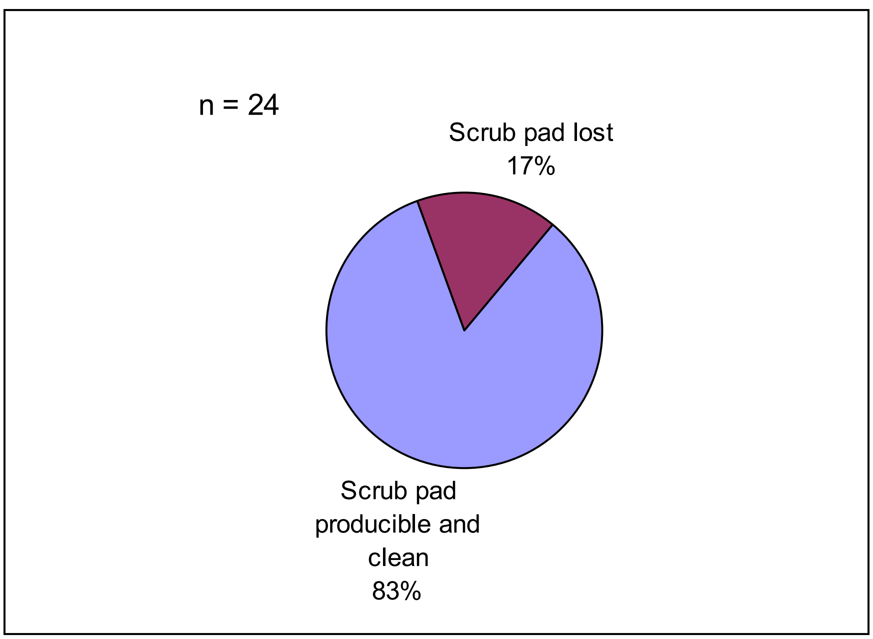


Figure 4.36 Scrub Pad Presence and Cleanliness

4.1.13 Cloth Pre-filter Cleanliness

Study participants commonly remembered to clean the cloth pre-filter: fourteen (14) of the twenty-four households (58%) reported cleaning the pre-filter between the first and second household visits (Figure 4.37).

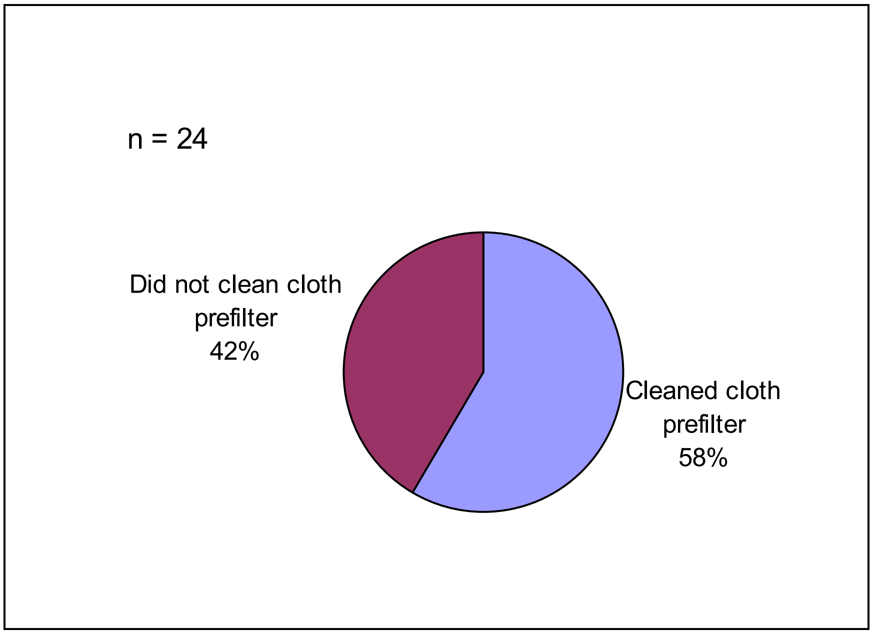


Figure 4.37 Cloth Pre-filter Cleaning Practices of Households between Household Visits

The cloth pre-filter becomes significantly dirty within a short time period only for households drinking highly turbid water. Dam HSW was typically the only source type featuring high turbidities, so it was especially important that households drinking dam water cleaned the cloth pre-filter regularly. All of the eleven (11) households drinking dam water at the time of at least one household visit reported having cleaned the cloth pre-filter during the period between the first and second visits. (Both of the households drinking non-dam source type water above 30 NTU - a rough estimate of highly turbid water - at the time of a household visit drank from dam water at the time of another household visit, and therefore were included in the eleven households above.) All cloth pre-filters of households drinking from low-turbidity piped, borehole and well sources appeared clean during both household visits.

4.1.14 Drinking Cup Associated with Filter

During the first household visit, study participants were requested to use one of their drinking cups only with the siphon filter, to prevent recontamination of filtered water by a dirty cup. All households complied with this request and provided a visually clean cup. However, it was not possible to determine whether these cups were the only implements used to fetch water from the lower containers during everyday use, or whether cups were used for other purposes when a household visit was not taking place.

4.1.15 Lower Container Cleaning

All households reported cleaning lower containers regularly, and many had a mechanism in place for cleaning. For example, many study participants cleaned upper and lower containers when upper containers became empty, which occurred in one case roughly every three days. However, the quality of the water used to wash lower containers was not studied and could impact the microbial risk of filtered water. Lower container cleanliness is discussed in section *4.2.7*.

4.2.16 Tube Kinking

An unexpected problem that occurred with the filter was that the rubber tube sometimes kinked. The rubber ring designed to enable shortening of the effective tube length allowed the tube to double over and restrict water flow if the tube was pulled taut in a certain way. This issue happened at five (5) households. I recommended cutting off the ring in these cases, which solved the problem. Figure 4.38 shows the percentage of households with tube kinking issues.

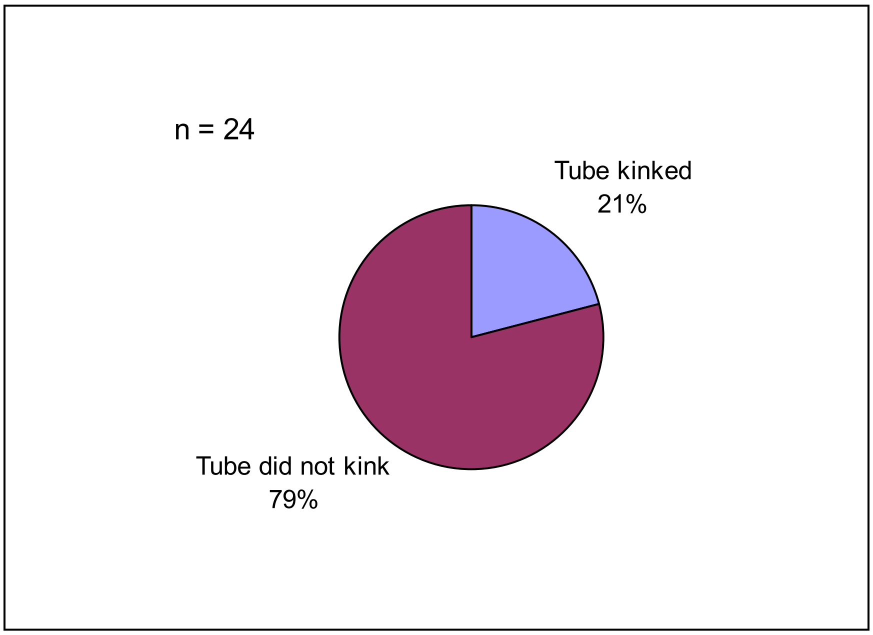


Figure 4.38 Percentages of Tube Kinking among Households

4.2.17 Filter Breakages

I encountered three (3) broken filters in my field work and was informed of two (2) other breakages by an MIT team testing another set of ten (10) siphon filters in the Brong Ahafo Region adjacent to the Northern Region of Ghana as an extension of this research. (The Brong Ahafo study is discussed in *Appendix E*.) Figure 4.39 shows all these breakages. None of the breakages involved the ceramic filter element itself, but were due to failures of various other filter pieces. One ceramic filter element completely detached from its plastic base due to faulty glue holding the two pieces together. Two filters broke during transport, snapping at the junction of the tube and the plastic base (this base connects the tube to the ceramic element). The filters were wrapped in the cardboard boxes in which they were sold in such a way that pressure from the top of the box snapped the plastic connection piece. Fortunately, the connection sections were long enough to allow the tubes to be reconnected, and these filters were successfully repaired. The remaining two breakages involved bulbs that ceased to create suction to carry water from the ceramic elements to the taps. Submerging these filters in water indicated no leaks; whatever the cause, flow rates were minimal and the bulbs did not function properly. The manufacturer is currently redesigning the bulb and is aware of these breakages.

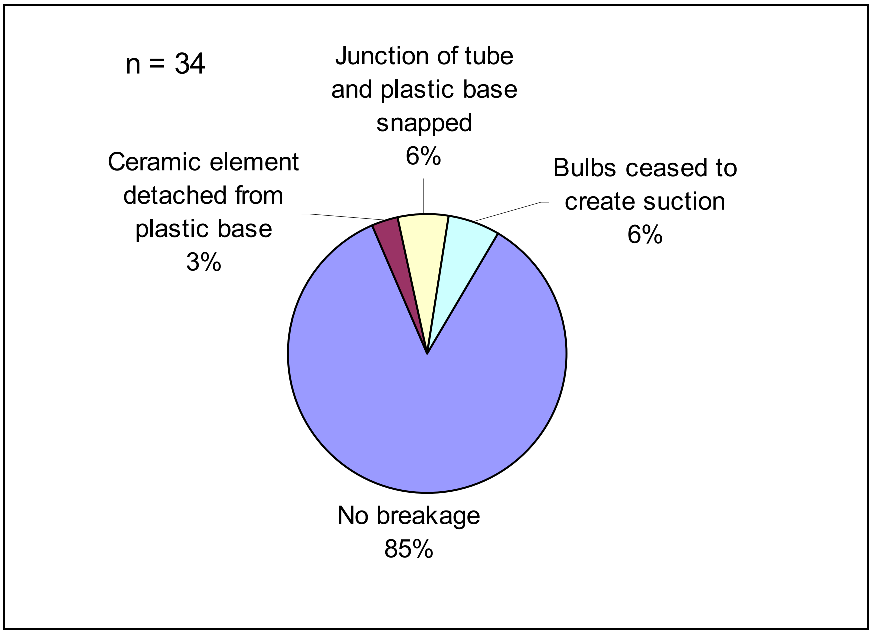


Figure 4.39 Filter Breakages

5. Discussion

5.1 Filter Performance

5.1.1 Total Coliform Removal and Possible Explanations for Siphon Filtered Water Contamination

For the studies undertaken at MIT, the average removal rate for total coliform was 98.3%, representing removal from 200-2,300 CFU per 100 ml (average value of 989 CFU per 100 ml, median value 800 CFU per 100 ml) to undetectable levels (<10 CFU per 100 ml) for all samples. Removal of total coliform in the MIT laboratory was consistently effective.

Removal to Undetectable Levels:
For the Ghana field study, total coliform was not always removed to undetectable levels. Of the forty-eight (48) total HSW samples, thirty-eight (38) samples showed detectable levels of total coliform contamination. Of these thirty-eight HSW samples showing contamination, 47% of corresponding SFW samples showed reductions to undetectable levels. Average percent removal of total coliform for these samples was 96.9%. HSW for the samples that showed reductions to undetectable levels had an average of 3,317 total coliform CFU per 100 ml, which is considerably higher than the levels tested at MIT. The filter proved it could be successful at removing these high levels of total coliform (up to 13,800 CFU per 100 ml) to undetectable levels below 10 CFU per 100 ml.

Removal to Detectable Levels:
However, fifteen (15) field samples (39% of samples showing detectable levels of total coliform in HSW) indicated incomplete removal. Average percent removal of total coliform for these fifteen samples was 83.4%. HSW in these cases ranged from 1,000-30,000 CFU per 100 ml, while SFW ranged from 10-3,700 CFU per 100 ml.

The five (5) remaining samples (13% of samples showing detectable levels of total coliform in HSW) showed increased or unchanged levels of total coliform in SFW versus HSW.

Two possible explanations for this are that recontamination of these samples may have occurred within the filter element due to bacterial growth, or through the filter tap, which often rested against the sides of lower water containers or submerged in lower container water, and which could also have been contaminated by dirty hands. The possibility of bacterial growth within the filter cannot be ruled out by this study; however, for the following reasons, recontamination by siphon filter taps is believed to be the chief cause of recontamination:

(1) Tests done by the independent lab Waterlaboratorium Noord and the MIT study found log 4.4-5.5 and log 1.9 reductions respectively for filter performance[15]. If

[15] Waterlaboratorium Noord used *E. coli* as an indicator organism, while the MIT study used total coliform.

filters performed similarly in Ghana, which seems reasonable to assume, then recontamination must have originated outside the filter.

(2) Recontamination of treated drinking water during storage is known to be a common problem in the field of household water treatment. For this reason safe storage is commonly regarded as having an essential connection to household water treatment. In the Ghana field study, contamination of lower water containers could have occurred through dirty hands or by "cleaning" lower containers with contaminated water. Only 13% of field study households had undetectable levels of total coliform in both HSW samples; the remaining households lacked reliably clean drinking water as determined by this criterion. Lower containers may therefore have been washed with contaminated water and could not be presumed clean. When informally questioned in the field study, users most often stated that they used the filter only for drinking; no study participants stated they used filtered water to clean dishes or the lower container. With the exception of the 13% of users with a reliably clean water supply, it is reasonable to assume that lower water containers were sometimes cleaned with contaminated water. Lower water contamination therefore seems likely to have existed in some cases for the field study, and since siphon filter taps usually rested against the inside walls of lower containers or submerged in lower container filtered water, contamination from the lower container could have transferred to the tap. Contamination could also have occurred by users touching filter taps with dirty hands; this contamination could have then transferred to lower containers.

(3) When samples for the field study were taken directly from the tap (to help avoid the possibly-contaminated lower container), coliform may have transferred from the tap to the water flowing through the tap and into the sample collection bag. In this way, lower container and tap contamination could have transferred to SFW samples. Recontamination through filter taps seems the likely cause of SFW samples that featured higher coliform levels than HSW samples.

(4) Furthermore, although the presence of recontamination was only obvious in cases for which SFW samples showed higher coliform levels than HSW samples, recontamination could have similarly taken place in many other samples. In these cases, percent removals would be less than the filter could potentially have shown without recontamination. This would imply that filter performance (i.e. contaminant removal before the filtered water exited the filter) could have been better in respect to coliform removal than field tests measured. If lower container cleanliness were improved (or if a new tap design helped prevent tap contamination), recontamination may be reduced and percent reductions improved.

Further research is needed to determine the possible cause(s) of the post-filtration recontamination observed in this study and to ensure that the recontamination issue is remedied (e.g. by way of a safe storage container or by changing the filter itself).

5.1.2 *E. Coli* Removal

Nearly all results showed *E. coli* removal to undetectable levels. Source samples studied at MIT ranged from 99-300 *E. coli* CFU per 100 ml, with an average value of 189 CFU per 100 ml. All corresponding siphon filtered water samples showed levels of *E. coli* below the detection limit of the Colilert® 10 ml pre-dispensed test (i.e. <10 CFU per 100 ml), corresponding to an average percent removal of 94.0%. For the Ghana field study, *E. coli* contamination was detected in 56% of household stored water samples. The average level of *E. coli* in household stored water was 274 CFU per 100 ml, which was similar to the average level found in the MIT study. However, *E. coli* contamination for the field study HSW ranged from 99-1500 CFU per 100 ml, a larger range including higher levels than the MIT study. Siphon filters in the field study showed removal to undetectable levels for twenty-four (24) of the twenty-seven (27) sample sets showing *E. coli* contamination. The other three (3) SFW samples showed increased or identical levels of *E. coli* compared to HSW samples, indicating possible recontamination or inadequate performance of these filters. If these samples are assumed to have been recontaminated by dirty taps (via contact with lower water containers or dirty hands), filters may have shown complete removal of *E. coli* in all cases.

5.1.3 Comparison to Published Coliform Removal Values

5.1.3.1 Waterlaboratorium Noord Siphon Filter Study

Charles River source water did not display high enough *E. coli* or total coliform levels to demonstrate log 4.4-5.5 removal using the siphon filter as shown by the Waterlaboratorium Noord tests (Wubbels, 2008), although the filter tested at MIT may have been capable of such removal. The *E. coli* average percent removal rate found at the MIT lab was 94.0%, and the average log reduction was 1.3. Similarly, coliform levels in the field were not high enough to show log 4.4-5.5 removal for the siphon filter. The *E. coli* average percent removal rate found in the field was 94.1% (excluding three samples for which SFW samples showed same or higher values of contamination as HSW samples).

5.1.3.2 Brown and Sobsey Ceramic Pot Filter Study

In their 2006 study in Cambodia, Brown and Sobsey found that 17% of their 203 total samples showed higher *E. coli* concentrations than untreated water, and they attributed this recontamination to improper filter cleaning and handling practices. Brown and Sobsey included these negative removal values in their average removal calculations. Since the pot filter features integrated safe storage, it made sense for this study to sample the microbial quality of post-filtration stored water (rather than to sample water dripping from the ceramic element before this filtered water reached the storage compartment) and to include any recontaminated (negative removal) values in their analysis. The siphon filter, on the other hand, does not feature safe storage, and so in order to measure filter performance without measuring the cleanliness of lower water containers (which were determined to be outside the siphon filter system boundary for the purpose of the study) filtered samples were taken directly from filter taps. This siphon filter study excludes negative removals from average removal calculations to attempt to leave lower water container cleanliness out of the filter performance analysis, assuming negative removal values were caused by recontamination through taps resting in dirty lower water containers.

5.1.4 Turbidity Removal

When the siphon filter is new, ceramic particles leach from the element and create increased turbidity of filtered water. The manufacturer recommends filtering twenty (20) liters through the filter to eliminate these particles before use. Once twenty liters were filtered in the MIT study, the siphon filter showed a high turbidity removal rate of 98.9%, resulting in filtered water turbidities of 2.19 NTU on average. Siphon filtered water from this study satisfied the statement in the WHO *Guidelines for Drinking-Water Quality* that turbidities of less than 5 NTU are usually acceptable to consumers (WHO, 2006).

Percent removals of turbidity in the field study were lower than found in the MIT study (81.2% average removal for dam water samples showing positive removal, and increased average turbidities for total filtered samples as compared to HSW samples). Turbidities of MIT study source water had an average of 329 NTU, while field study HSW samples had lower average turbidities of 106 NTU for dam water and 8.0 NTU for other source water types. It is therefore reasonable that removals for the field study were less dramatic than removals found in the MIT study, due to lower pre-filtration water turbidities. The additional effect of ceramic particle leaching also contributed to low percent removals (and indeed to increased turbidity after filtration), as study participants were not asked to filter twenty (20) liters of water through the siphon filter before use.

Ceramic particle leaching can create a possible unpleasant taste of filtered water, in addition to increased turbidity of filtered water, as compared to raw water. However, ceramic particle leaching only arose as an issue for user acceptance of the siphon filter for one household. This study participant commented on the "bitter" taste of filtered water during the first household visit, and had not used the filter more than once. The participant did not filter twenty liters through the filter to try to fix this taste issue within the week after this was suggested.

5.2 Safe Storage Post-Filtration

Assuming that recontamination of lower water containers through siphon filter taps is responsible for inferior filter performance in the field (see section *5.1.1 Total Coliform Removal and Possible Explanations for Siphon Filtered Water Contamination*), improving the cleanliness of the lower water container by using a safe storage container as a lower water container could reduce contamination and improve the quality of filtered water after it exits the tap. However, regardless of whether recontamination of filter taps through lower water containers caused decreased filter performance in the field study, lower water container cleanliness is crucial to ensure safety of filtered water at the time of consumption.

The importance of safe storage used in conjunction with the siphon filter cannot be overemphasized. The lower water containers used by households in Ghana were usually uncovered buckets or jerry cans, neither of which ensures safe storage of siphon filtered water. Uncovered buckets allow users to touch the inside of the container with dirty hands or to fetch water from the inside of the container with a dirty implement, both of which are actions that can cause contamination. While jerry cans feature a relatively small hole that helps prevent hands or implements from reaching inside the container, the hole does allow users to stick fingers inside (which is sometimes necessary to adjust the siphon filter tap, e.g.), which could contaminate the container. The small hole also makes cleaning jerry cans difficult. Cleanliness is especially difficult to ensure because jerry cans are often reused after containing other liquids. Another issue with both the buckets and jerry can is that the extreme dust found in the dry season in Northern Ghana tends to settle into these containers through the open tops.

Lower containers such as uncovered buckets and jerry cans can become contaminated through dust, dirty hands or by "cleaning" these containers with contaminated water. Many study participants were seen on household visits rinsing lower water containers or cups with household stored water; microbial indicator tests of household stored water showed contamination in 79% of cases (section *4.1.2.2.1 Total Coliform*). If the goal of using the siphon filter is to provide people with safe water, the system cannot stop at the tap: lower water container cleanliness must be addressed.

5.2.1 Method 1: Replace Lower Container with Cup

A possible mediation for the issue of post-filtration recontamination could be to eliminate the lower water container altogether, and instead to suggest that users provide a single clean cup to be associated with the filter. This method is perhaps the simplest, but it may not be the best. Without a lower container, users would close the siphon filter tap until they desired to drink, at which point they would open the tap and wait for the cup to fill. Ghana field study participants were encouraged to use a single clean cup with the filter, with the assumption that users need an implement to drink filtered water even with the presence of a lower container as an intermediary. Removing the lower container would eliminate one possible cause of contamination. However, this method would not allow users to filter large amounts of water at once or to filter water while completing other tasks, which are important aspects of filter use. Moreover, eliminating the lower water container may encourage more frequent touching of the tap with potentially dirty hands. For these reasons, a safe storage container is believed to be a superior method of reducing contamination of filtered water.

5.2.2 Method 2: Siphon Filter Safe Storage Container

Another solution to post-filtration contamination could be to market a small safe storage container with the filter. The Delft Institute of Technology Tanzania study concluded that safe storage was a necessary addition to the siphon filter product, and their recommendation was a safe storage lower bucket to which the siphon filter tap would connect (Tanzaniaqua, 2008). A similar safe storage lower container is proposed here. An ideal safe storage container to be used with the siphon filter would:

(1) prevent hands and implements from touching the inside of the container;
(2) feature a mechanism to withdraw water from the container without touching the inside;
(3) facilitate easy cleaning of the container;

(4) hold enough filtered water for everyday use without holding so much as to encourage long-term storage of filtered water, which could lead to regrowth of microbial contaminants; and
(5) prevent dust from settling into the container.

The proposed safe storage container accomplishes these goals.

A suggested volume for the container is 2-5 liters. The proposed container, shown in Figure 5.1, features a screw lid that removes to allow easy cleaning of the container, and when closed during use prevents hands and implements from contaminating water. A tube connecting a small hole in the lid to the siphon filter tap[16] would help prevent dust, dirty hands or water from contaminating the tap. This tube would be the same type as the siphon filter tube. An alternate way to connect the siphon filter tap to the storage container lid could be to directly place the end of the tap into a hole in the container lid the same size as the end of the tap. However, using a tube to connect the lid to the tap is anticipated to make tap use easier by providing more space between tap and lid, as well as to provide a more stable connection between tap and lid. To clean the safe storage container, the tube would be disconnected from the tap in order to easily unscrew the lid. A storage container tap at the bottom of the container permits hygienic removal of water. This safe storage container could better ensure that siphon filtered water remained safe up to the point of use.

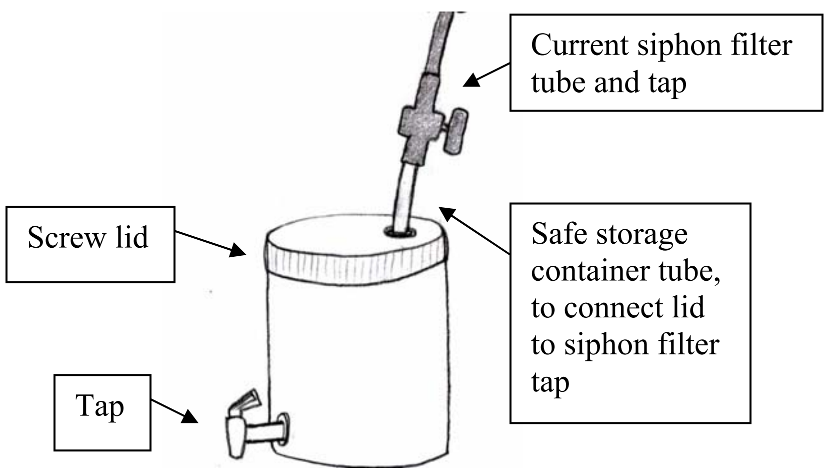


Figure 5.1 Possible safe storage container design

Users could have the options to buy this container with the filter or to use their own lower water container instead. Providing the option of a simple safe storage container with the filter would give consumers the option of controlling the quality of their filtered water more easily. The siphon filter could be distributed inside the safe storage container to conserve space.

[16] The Tanzaniaqua team from the Delft Institute of Technology originally suggested a safe storage container with a connection in the lid for the siphon filter tap (Tanzaniaqua, 2008).

Regardless of the type of container used to fetch water from the siphon filter (e.g. cup or safe storage container), users should wash this container only with siphon filtered water (or with water disinfected using another method such as chlorination) to prevent contamination. Since the siphon filter features a flow rate of 3-5 liters per hour, it seems users should have enough water to adopt this practice.

5.2.3 Method 3: Hooded Siphon Filter Tap

Another idea for preventing recontamination of siphon filtered water was proposed by the Delft Institute of Technology team working in Tanzania with the siphon filter. Their redesign of the siphon filter tap (see Figure 2.10) adds a cylindrical hood over the opening of the tap to help prevent dirty hands from contaminating water flowing out of the tap, and a tap lever that could hook onto the side of a lower water storage container, helping prevent contamination from transferring between the lower container and tap (Tanzaniaqua, 2008). This method is not a replacement for a safe storage lower water container, as a redesigned tap would not help prevent contamination of lower containers by touching with dirty hands or by washing with contaminated water. However, by helping to prevent contact of the tap with dirty hands and with potentially dirty lower water containers, this tap redesign mitigates contamination.

Further research of the siphon filter with a safe storage container or with a redesigned filter tap could determine whether these methods of post-filtration recontamination prevention were effective.

5.3 Siphon Filter Applicability for Low versus High Turbidity Water

Using the siphon filter is easiest with low-turbidity water. Although maintenance steps such as backwashing and pre-filter washing help to lengthen filter element life for filter use with all types of water, flow rates may remain high for a substantial period of time even if users drinking low-turbidity water do not regularly practice these tasks. The filter generally needs to be scrubbed less frequently with low-turbidity water because fewer particles clog the ceramic element. Additionally, low-turbidity water does not need to settle before filtration. The siphon filter is well-suited to use with low-turbidity water. Note that out of ten (10) households drinking piped water supplies for both household visits, only one (1) household (10%) showed undetectable levels of total coliform in both HSW samples, and 60% of these households showed greater than 10 CFU per 100 ml for *E. coli* (indicating intermediate risk or higher) in at least one HSW sample. This indicates that the siphon filter is appropriate for use with piped water supplies (as well as other low-turbidity source water types) in Northern Ghana.

In contrast to siphon filter use with low-turbidity water, filter use with turbid water is more difficult as maintenance steps are crucial and various. The issues of whether Pure Home Water should market the siphon filter to users drinking highly turbid water and how to best encourage filter use with turbid water are vital: households drinking turbid water are among the most in need of a reliable household water treatment system (in Northern Ghana specifically, but also in other areas of the world still drinking unimproved surface water supplies) since this water is often highly contaminated. Options for siphon filter use with highly turbid water include the following, which are examined in more detail below: (1) providing detailed instructions and specialized training in proper filter use and maintenance for potential buyers; (2) pre-filtration settling; and (3) alum (or other coagulant) pre-treatment.

5.3.1 Training and Instructions

Siphon filter use with turbid water can be discouraging for users: frequent clogging can deter people from continuing use, and the processes necessary to prevent clogging require diligence. If users do not regularly backwash, settle turbid water before filtration and scrub gently only when having backwashed multiple times without flow rate improvement, then filter elements are likely to clog frequently and/or wear out prematurely. Even when these practices are carried out appropriately, there is little evidence of how long siphon filter elements last under turbid water conditions. In order to maximize the likelihood of successful filter use, it seems appropriate only to market the filter to users willing to devote themselves to completing these practices. Since study participants infrequently understood and practiced the maintenance tasks associated with the siphon filter, it seems unreasonable to assume all potential buyers are prepared to diligently maintain the filter under turbid water conditions. Rather, PHW or other organizations selling the siphon filter should carefully explain the siphon filter and all of its maintenance requirements to potential buyers, and ensure that buyers are prepared and willing to perform all necessary functions before purchasing of the filter; sellers should do this for all potential siphon filter buyers, but especially for those drinking turbid water. This means that organizations selling the siphon filter need to be well versed in the operation and maintenance of the filter, in order to be able to explain it to potential buyers. In addition, siphon filter literature can provide assistance for educating both sellers and buyers. (*Appendices A* and *D* show a pictorial guide and a technical instructions sheet, respectively.)

5.3.2 Settling Water

Settling water for an hour before filtration is a relatively easy way to reduce turbidity and to help reduce filter clogging. Roughly a third of users drinking highly turbid water adopted the practice of settling water. These users were explicitly requested to settle their water so the siphon filter would need to be scrubbed less, resulting in a longer filter life. Settling water before filtration requires time and advanced planning on the part of the user, which may deter some users from adopting the practice. However, settling should nevertheless be advised to filter users drinking turbid water, as the practice is a simple way of lengthening filter life with no additional cost.

5.3.3 Coagulation Pre-treatment

Another possible aid to decrease the frequency of siphon filter clogging with turbid water is coagulation using a product such as alum. Adding a coagulant helps remove particles from water by causing smaller particles to clump together into larger agglomerations due to electrochemical reactions, and therefore to settle more quickly to the bottom of a container. Alum balls are sold in Northern Ghana for reasonable prices (less than US$4.50 per year), and are typically used in households when drinking water is considered to be particularly turbid. Using alum before siphon filtration of highly turbid water would be expected to considerably reduce the necessary frequency of scrubbing by removing a large fraction of particles from water before it reached the filter element. (The practice of setting water for one hour before filtration removes some particles, but coagulation would remove a much larger fraction.) However, coagulating water requires additional money and effort as well as a reliable supply chain to provide the product to consumers, and may not be acceptable to consumers for these reasons. Additionally, some users dislike the taste of alum-treated water, and some users report alum causing diarrhea (likely caused by overdosing) (Swanton, 2008). Since about two-thirds of users did not adopt the settling process, organizations marketing the siphon filter should not presume that coagulation would be readily adopted either.

The siphon filter on its own requires several maintenance practices, and adding coagulation may make the entire process too complicated for many users to perform (due to lack of understanding or inclination). Additionally, although coagulation is expected to lengthen filter element life, the siphon filter may operate satisfactorily without this step as long as users are diligent about other filtration steps (including backwashing and settling). Therefore, expecting all users of turbid water to coagulate may be unrealistic. Pure Home Water should only encourage potential buyers that drink turbid water to purchase alum balls to coagulate if individual buyers are committed to adding this process to the filtration routine.

5.4 Siphon Filter Applicability for Lower- versus Middle-Class Households

No clear distinction between effective use of the siphon filter in middle- versus lower-class households (classification based on house type) was found by this study. No relationship was found, for example, between understanding the backwashing process and class level. Although households drinking highly turbid water were often lower-class and households drinking piped water were often middle-class, distinctions made regarding filter use for these households pertain to source water quality rather than class level.

5.5 Effective Use Issues

5.5.1 Clay Pots as Upper Containers

Large clay pots were often used as upper containers, as these were traditional water storage vessels. These containers could not easily be elevated to the recommended height due to weight, size and fragility. Households may also have lacked sufficient materials to elevate these containers in some cases. In general, elevated clay pots do not seem realistic for these reasons and because they would be difficult to load with water if their bases were elevated, for example, to table-top height. Using a large clay pot (sitting at ground level) as an upper container is not ideal because the distance between the upper container water level and siphon filter tap is typically less than ideal, resulting in reduced flow rates. However, using these vessels as upper containers is the reality for rural and even many urban households in Ghana.

Water storage pots are typically tall enough that as long as water levels are kept near the tops of these containers, distances between water levels and siphon filter taps are likely sufficient. Households typically top off water storage pots regularly, so that maintaining sufficient distance between upper container water level and tap is usually possible. Shorter lower water containers also help facilitate larger distances between upper container water levels and taps, since in this case taps can be closer to the ground. Jerry cans, which were frequently used as lower containers in the field study, are taller than other typical lower containers (such as small buckets) and are therefore disadvantageous in this respect. A pictorial diagram illustrating an upper container water level well above the siphon filter tap is expected to be clear enough to show users to maintain this distance. Showing a raised upper container will encourage users to elevate containers if possible, but since many users in Ghana are using large clay storage vessels, the instructions should be tailored to these local circumstances.

5.5.2 Filter Housing

Ninety percent (90%) of study participants (who were using the filter at the time of the first household visit) had not removed the housing jar before use. Because housing removal does not seem to be intuitive, filter literature should state this direction.

Housing was often used as a home storage container for the scrub pad. This is a suitable use, as housing is generally not used for other purposes once the filter has arrived safety to the home, meaning the housing is likely to be clean. Because the housing features a small hole in the bottom (presumably to allow airflow for drying the filter element and cloth pre-filter during storage), housing is not suitable for use as a drinking-water cup.

5.5.3 Children Tampering

The siphon filter ordinarily allows users to filter large amounts of water at once with minimal attention to the device during filtration. If children tamper with the device, however, users must constantly pay attention to the filter or put it away when they need to leave the premise or attend to other tasks. Several households had difficulties with children tampering with the siphon filter during use, which was often outside where children played. Some study participants brought the filter inside for storage when they could not watch the filter. This remedied the issue of children tampering with the filter, but limited participants' access to readily available drinking water.

As children seemed to play primarily outdoors, a possible solution to this issue could be to move the siphon filter set-up indoors. This could only work well if users had enough space in homes for two water containers. Five (5) study participants (21%) did use the filter indoors, one (1) of whom used a large clay pot as an upper water container, probably indicating that filter use indoors is socially acceptable. Using the filter indoors may allow users to protect the filter from children while being able to devote attention to other household tasks. For users who do not have space to move the filter set-up indoors, a relatively secluded spot is ideal for filter placement to avoid tampering.

5.5.4 Over-scrubbing

Eight (8) study participants (33%) reported scrubbing the filter during the study. None of these participants had backwashed the filter before scrubbing. All of these participants used dam source water (generally highly turbid) during one household visit, and six (6) households used dam source water during both household visits. The filter may have clogged due to this highly turbid water. However, the filter should not have been scrubbed until backwashing had been tried and failed to restore the flow rate. Two (2) participants had scrubbed much more ceramic material from the filter element than seemed necessary. These study participants may have thought they needed to scrub the filter to keep it clean as regular maintenance, or that they needed to remove a large portion of ceramic material to effectively unclog the filter to restore flow rates. Over-scrubbing the filter element may drastically shorten the life of the filter, and users must be cautioned to gently scrub only when necessary (i.e. when backwashing does not restore flow). Both siphon filter literature and sellers should make this clear. However, clarifying when scrubbing should occur and how hard to press is difficult using pictorial diagrams; therefore it is quite important that sellers ensure that buyers understand scrubbing well.

5.5.5 Scrubbing versus Backwashing

Arguably the most important practice for extending filter life is backwashing, as it reduces the frequency of necessary scrubbing. Only 25% of total users and 36% of users drinking turbid water remembered how to backwash during the second household visit, and only 13% of users reported having backwashed during the study period. This is significant because lack of backwashing directly leads to reduced life of the filter element through increased scrubbing. Additionally, only 25% of total participants understood the correct procedures for both backwashing and scrubbing, including that one scrubs only when backwashing fails to restore the flow rate. In contrast, study participants more easily understood that scrubbing was a way to clean the filter and to restore flow rate. Thirty-three percent (33%) of households performed scrubbing during the study period. (None of these users backwashed before scrubbing.)

Scrubbing may be a relatively intuitive practice, because households clean dishes and other objects in everyday life by scrubbing them. Backwashing, on the other hand, is a less familiar concept. Showing users that water inside the filter was being forced out by squeezing the bulb (by taking off the pre-filter and watching water drip out of the ceramic element) seemed to help explain the backwashing process. However, either because the practice was difficult to remember how to do, or because users did not understand why it was important, users tended to backwash less frequently than advised. Especially for users drinking turbid water, neglecting backwashing will result in increased frequency of scrubbing and reduced lives of filter elements.

5.5.6 Comparison to Delft Institute of Technology Issues

Some of the issues found by the Delft Institute of Technology study in Tanzania with the first version of the siphon filter were also encountered in this thesis study with the second version of the filter. Both studies found that the backwashing procedure was difficult to understand and that many participants did not easily associate backwashing with cleaning the filter. However, while many participants in the Tanzania study backwashed the filter to rid it of water before storage (rather than to clean the filter), this practice was not observed in the Ghana field study. Both studies found that scrubbing the filter to clean it was more easily understood than backwashing.

Another common issue between the two studies was difficulty using the loop to adjust the height of the tap relative to the lower container. One manifestation of this difficulty in the Ghana field study was kinking of the tube, though this particular issue was not addressed by the Tanzania study.

Lastly, both studies identified recontamination of siphon filtered water as an issue. Dirty hands and dirty lower water containers were thought to be major causes of possible recontamination. Both studies recommend a safe storage container for the siphon filter as well as a redesign of the filter tap to help prevent contamination of filtered water (Tanzaniaqua, 2008), as discussed in sections *5.2.2* and *5.2.3*.

Although the Delft Institute of Technology study in Tanzania and this thesis project study in Ghana had the above issues in common, each study encountered several unique issues. Siphon filter use in the two countries was probably influenced in part by culture, as well as by particular explanations of filter use and maintenance to study participants.

6. Recommendations and Conclusions

6.1 Filter literature

Siphon filter literature should be disseminated with siphon filters and used as teaching tools for potential buyers. Two forms of literature are provided in this thesis.

- The *Instructions for Use* sheet (Figure 2.9; modeled after the BWN IU guide, 2008) would be especially helpful for teaching Pure Home Water employees about the filter, as well as users who can read English.

- Pictorial instructions would be most helpful for the majority of siphon filter users, as these instructions are simple and do not require reading ability. However, it is especially important that these pictorial instructions be used as a supplement to Pure Home Water employee instruction, rather than as the primary mode of learning about the filter. This is because some elements of filter use are not easily expressed succinctly by pictures (e.g. the importance of only scrubbing the filter if backwashing has been attempted and does not restore flow rate). The pictorial instructions provided in *Appendix A* are specific to a conventional set-up: the upper container depicted is a bucket, which is elevated to table height. A second set of pictorial instructions should be developed that replaces this upper container depiction with a large clay pot used at ground level. This set-up is a reality for many rural and even urban households in Northern Ghana, and a specific pictorial diagram could address issues that arise with the set-up, namely the upper container water level sinking near to (or below) the level of the tap and reducing (or eliminating) flow rates.

One set of pictorial instructions should be given to users depending on whether their anticipated set-up will involve an elevated upper container (the "conventional" set-up) or a large clay pot at ground level. If users can read English, *Instructions for Use* instructions should be given to users as well. Additionally, PHW could translate the guides into local languages.

6.2 Filter Instruction

Although filter literature is helpful for understanding filter use and maintenance practices, both at the time of initial use and in the home throughout use, Pure Home Water should provide instruction to potential filter buyers through demonstrations of filter components and practices. It is important that users understand how to use the filter before purchasing it, to ensure the technology is right for them. PHW salespeople and trainers should also be able to answer any questions that arise while potential users learn about the filter.

6.3 Potential Marketing Groups

6.3.1 Socioeconomic Level

The results of this study indicate that the siphon filter is equally applicable to lower- and middle-class households in Northern Ghana. Although lower-class households surveyed in this study more often drank high turbidity water, issues involving siphon filter use in these households were found to be a function of water type rather than of class level.

6.3.2 Households Drinking Low Turbidity Water

The siphon filter is recommended for users with low turbidity water of any kind. Piped water in Northern Ghana has been shown to be unreliable in terms of quality (see sections *5.3 Siphon Filter Applicability for Low versus High Turbidity Water* and *4.1.2.1 Source Water Characterization*), and is also unreliable in terms of consistent delivery. Therefore the siphon filter is appropriate for use with piped water as well as dug well and borehole water, which are typically low turbidity (i.e. roughly under 30 NTU).

Pure Home Water employees should explain the filter to all potential customers using a specialized siphon filter demonstration, and filter literature should be disseminated both during the demonstration and with the filter to buyers. While it is important for all users to understand filter use and to practice maintenance tasks such as backwashing, these tasks are not quite as crucial with low turbidity water. Additional practices such as settling and coagulation are not necessary for filter use with low turbidity water.

6.3.3 Households Drinking High Turbidity Water

Highly turbid water is defined for this study as showing greater than 30 NTU. The siphon filter is recommended to users drinking high turbidity water under the following conditions.

Because regular maintenance practices such as backwashing, settling, and washing the pre-filter are vital for siphon filter use with highly turbid water to avoid frequent scrubbing and short filter element lifetime, Pure Home Water should only sell the filter to potential users who understand the filter and who are willing to perform maintenance tasks diligently. Settling and backwashing are especially important maintenance practices for highly turbid water, and filter buyers drinking turbid water should be willing to perform these regularly. In order to ensure customers understand what filter use and maintenance entails, Pure Home Water employees should explain the filter to potential customers using demonstrations and provide filter literature as a teaching aid. If users are willing to perform maintenance tasks regularly and have been taught how to do so, the siphon filter shows potential to work for highly turbid water.

6.3.3.1 Pre-Filtration Coagulation with Alum

Coagulation of highly turbid water is expected to significantly lengthen siphon filter element life by removing a substantial fraction of particles from water before filtration, thereby decreasing the frequency of necessary scrubbing. Alum is a coagulating agent that is available for affordable prices in Northern Ghana, and is widely used to reduce the turbidity of unusually turbid waters. While coagulating with alum is expected to aid filter use with turbid water, the practice would cost additional money, time and effort. Therefore, Pure Home Water should explain and encourage coagulation with alum to potential siphon filter users drinking highly turbid water, but should not discourage siphon filter use altogether if users do not wish to adopt this practice.

6.4 Safe Storage Container

In order to protect the quality of siphon filtered water and to better ensure the microbial quality of filtered water at the point of consumption, a safe storage container should be marketed with the siphon filter. The proposed safe storage container (Figure 5.1) accomplishes the goals laid out in section *5.2.2 Method 2: Siphon Filter Safe Storage Container*. Any safe storage container marketed by Pure Home Water should address these goals. Users should be encouraged to purchase a safe storage container with the siphon filter, although they should be given a choice to use their own lower safe storage container instead. Safe storage should be emphasized in the Pure Home Water siphon filter demonstration. PHW should also instruct users to wash their safe storage containers with siphon filtered water (or with water disinfected by another method) to prevent contamination.

6.4.1 Further Research with Safe Storage Container

A further research study using a safe storage container with the siphon filter is recommended to help confirm the source of post-filtration recontamination found in the current study. If this future study showed that safe storage prevented or greatly diminished recontamination of siphon filtered water, then the siphon filter would be shown to be a more reliable treatment technology.

6.4.2 Tap Redesign

In addition to marketing the siphon filter with a safe storage container, a redesign of the siphon filter tap, as proposed by the Delft Institute of Technology team working in Tanzania and as discussed in section *5.2.3*, is recommended to the designers and manufacturers of the siphon filter to help prevent recontamination of siphon filtered water. This redesigned tap (or another similar design) would help to prevent contact of the tap with dirty hands and with potentially dirty lower water containers. The combination of the proposed tap and a safe storage lower container for the siphon filter is expected to substantially improve quality of siphon filtered water.

6.5 Siphon Filter versus Other Treatment Options

The siphon filter is one of several water treatment options applicable for Northern Ghana. These treatment options each have advantages and disadvantages that make them more useful for some groups of users than for others. The treatment options analyzed here are established options considered for marketing by Pure Home Water.

6.5.1 Kosim Ceramic Pot Filter

The primary treatment technology marketed by PHW is currently the *Kosim* ceramic pot filter, which costs roughly US$18. This filter works well for removal of contaminants, and features an integrated safe storage container. However, the *Kosim* filter sometimes breaks during household use, and its large size also makes distribution difficult. The *Kosim* filter has a slow flow rate and has a similar problem as the siphon filter with clogging for highly turbid water. Maintenance practices of the filters are similar, although the *Kosim* filter does not offer a backwash or pre-filter option. Notable advantages and disadvantages of the *Kosim* and siphon filter are compared in Table 6.1.

Backwashing and the pre-filter may make the siphon filter a better option for high turbidity water than the *Kosim* filter, which has a low flow rate even with low turbidity water. These siphon filter cleaning options prevent premature scrubbing and elongate filter life, but these practices can be difficult to understand. A long-term comparative study would be necessary to determine relative filter lifetimes and user acceptability.

The siphon filter is smaller and lighter than the *Kosim* filter, making distribution considerably easier. Siphon filter breakage did occur during the field study to a fairly substantial degree (15% of all 34 filters studied in the Northern and Brong Ahafo Regions), but breakage issues that arose during the study will be addressed in the third version of the filter. If the siphon filter were marketed with a safe storage container to maintain the quality of filtered water and if the siphon filter post-filtration recontamination issue were resolved, the siphon filter would be a suitable alternative to the pot filter. The choice would depend on whether users desired an integrated design with fewer maintenance practices (*Kosim*) or a smaller filter with higher flow rate and lower cost (siphon).

Table 6.1 Advantages and Disadvantages of the *Kosim* Pot Filter versus the Siphon Filter

Treatment Option	Advantages	Disadvantages
***Kosim* Pot Filter**	Integrated safe storage	Cost (≈ US$18)
	Simpler	Frequent breakage in homes
		Large, heavy
		Slow flow rate (0.5-2.5 L/hour)
		No mechanism to prevent clogging besides scrubbing
Siphon Filter	Inexpensive (Future version ≈ US$5)	Safe storage not included
	Relatively low breakage (anticipated improvements in future model)	Maintenance more complicated
	Small, light	
	Fast flow rate (≈ 3-5 L/hour)	
	Mechanisms to prevent premature clogging	

6.5.2 Chlorination: Low Turbidity Water Option

Chlorination is an effective method of disinfecting low turbidity water. Chlorine Aquatab brand tablets available in Northern Ghana provide a simple method of chlorine dosing for household use. Once chlorine is dosed, treated water retains a residual level of chlorine that maintains bacterial quality of water for a few days, which is an advantage over the siphon filter. However, safe storage is possible with the siphon filter through use of a safe storage container. The WHO recommends a contact time of at least thirty (30) minutes, which requires users to wait before drinking treated water. The siphon filter features a relatively fast flow rate and filtered water can be used immediately. Another disadvantage of chlorine is that it is not effective for high turbidity water, as particles can protect microorganisms from disinfection and can give rise to a significant chlorine demand. Chlorine can also react with natural organic matter in water to produce disinfection byproducts that can be carcinogenic; however, the risk from these compounds is generally less severe than the risk from microbial contaminants in drinking water (WHO GDWQ, 2006). Notable advantages and disadvantages of chlorination and the siphon filter are compared in Table 6.2.

According to the manufacturer, the siphon filter can treat 7,000-10,000 liters of water before the ceramic element needs to be replaced, depending on the turbidity of the water (BWN-SFFS, 2008). This corresponds to 1-1.5 years of use for a family of 2.5 people using 7.5 liters per day as recommended by the World Health Organization (WHO, 2006). To compare the costs of the siphon filter and other treatment options, a value of 7,000 liters per year was used for all treatment options. The third version of the siphon filter will cost roughly US$5 (Holtslag, 2008), plus US$3-4 dollars each 1-1.5 years to replace the ceramic element (BWN-SFFS, 2008), and is being designed to last at least five (5) years (i.e. the plastic parts of the filter other than the ceramic element) (van der Ven, personal communication, 2008). A cost of roughly US$4 per year for the siphon filter was calculated[17]. It would cost roughly US$10 per year to treat 7,000 liters of drinking water per year with Aquatabs[18]. Chlorine treatment is therefore more expensive than siphon filter treatment for low turbidity water.

Another disadvantage of chlorine is that people in Northern Ghana tend to value durable products that only require one purchase for long-term use, compared with consumable products that must be repeatedly purchased (Green, 2008). The siphon filter is advantageous in this respect.

For these reasons, the siphon filter is believed to be a better treatment option than chlorination for users drinking low turbidity water and potentially for users of high turbidity water, with the caveats discussed above (e.g. if the siphon filter recontamination issue is resolved). While the siphon filter requires more extensive maintenance than chlorination, these steps are worth the immediate access to treated water without disinfection byproducts and for a lower long-term cost.

[17] This value includes a cost of US$5 per year for a new siphon filter, plus US$3 per year for a replacement ceramic element.

[18] A cost of US$0.03 was used for each 67mg Aquatab, which is the price charged by the manufacturer. Each 67 mg Aquatab treats 20 liters of non-turbid water (Swanton, 2008).

Table 6.2 Advantages and Disadvantages of Chlorination versus the Siphon Filter

Treatment Option	Advantages	Disadvantages
Chlorine	Simple	Higher cost (≈ US$10/year)
	Low-maintenance	Wait required
	Residual protects treated water	Not appropriate for high turbidity
		Disinfection byproducts
		Consumable, requires multiple purchases for long-term use
Siphon Filter	Lower cost (≈ US$4/year)	Maintenance required
	Little wait required for treated water	Treated water can become recontaminated post-filtration
	Can work for highly turbid water	
	No disinfection byproducts	
	Buy only once for long-term use	

6.5.3 Alum plus Chlorine: Highly Turbid Water Option

While chlorine on its own does not work well for users with highly turbid water, alum can remove turbidity to allow chlorine disinfection to work more effectively. The alum plus chlorine option has similar disadvantages to straight chlorine: a wait is required before treated water can be drunk; the products are consumable, meaning multiple purchases are necessary; and disinfection byproducts are also a (relatively minor) issue. A wait is also required for siphon filter use with highly turbid water, as users must settle water before filtration. Other disadvantages to alum are that many people in Northern Ghana do not like the taste, and that some people report alum causing diarrhea. Aquatabs could improve the taste of alum-treated water (users report liking the taste of Aquatab-treated water), and as diarrhea is likely caused by excessive doses of alum (Swanton, 2008) this issue could be rectified by training users in proper dosing or by selling the product in appropriately pre-measured amounts. Alum does require manual stirring and pouring of treated water, which are significant tasks. However, these tasks are probably comparable to the siphon filter's maintenance requirements for turbid water. Notable advantages and disadvantages of alum plus chlorine and the siphon filter are compared in Table 6.3.

The choice between alum and chlorine versus the siphon filter for users of turbid water is not obvious. Regarding cost, the third version of the siphon filter would be less expensive when used long-term (i.e. over a year) than alum and chlorine, based on a price of US$4 per year for the third version of the siphon filter and US$12 per year for alum and chlorine[19] (a value of 7,000 liters per year was again used as in section *6.5.2*). However, the maintenance requirements of the siphon filter may deter some users from the filter and toward the relatively simple and culturally familiar coagulation/chlorination process. If the siphon filter recontamination issue is resolved, Pure Home Water should offer potential users drinking highly turbid water a choice between alum plus chlorine and the siphon filter.

Table 6.3 Advantages and Disadvantages of Alum plus Chlorine, the Siphon Filter and Alum plus the Siphon Filter

Treatment Option	Advantages	Disadvantages
Alum plus Chlorine	Simple Low-maintenance Residual protects treated water More effective for turbid water	Higher cost (≈ US$12/year) Possible taste issue Disinfection byproducts Consumable, requires multiple purchases for long-term use
Siphon Filter	Lower cost (≈ US$4/year) No disinfection byproducts Buy only once for long-term use	Maintenance required Treated water can become recontaminated post-filtration Less effective for turbid water
Alum plus Siphon Filter	More effective for turbid water No disinfection byproducts	Possible taste issue Consumable, requires multiple purchases for long-term use Higher long-term cost

Some users may also combine coagulation with siphon filter use, creating a third option. This option is comparable to using the siphon filter with the settling practice, except that alum is expected to be more effective than settling, while alum costs additional money, requires regular purchasing and may cause a negative taste issue. Adding alum to the price of the siphon filter is expected to make the total cost roughly similar to the price of alum plus chlorine over a long period. Pure Home Water should encourage alum as a supplement to the siphon filter to elongate filter life.

There are numerous other treatment options that may be applicable to Northern Ghana, including biosand filtration and community-scale treatment options, which are beyond the scope of this thesis but which Pure Home Water may want to consider.

[19] A cost of US$0.02 per alum ball was used. Each alum ball treats 80 liters of highly turbid water.

6.6 Conclusions

The siphon filter is a potentially effective and useful device for Pure Home Water customers drinking both low turbidity and high turbidity source waters. All nine (9) siphon filtered water samples studied at MIT showed *E. coli* levels of at most 9 CFU per 100 ml, corresponding to a low risk according to the WHO guidelines (WHO, 1997). Similarly, all but three (3) filtered samples studied in Ghana (89% of the 27 household stored water samples showing *E. coli* contamination) showed *E. coli* levels corresponding to a low risk level. The other three samples showed risk levels of intermediate, high, and very high risk, probably due to post-filtration recontamination of filtered water. Before PHW markets the siphon filter, further research should confirm the source of post-filtration recontamination and this issue should be remedied. Additionally, the siphon filter may not be the most appropriate choice for all customers, and other options have been reviewed in section *6.5*. Rather, the siphon filter should be integrated into the PHW product offering and presented to potential customers as one possibility among others for water treatment. PHW should present a small selection of the most appropriate technologies for individual customers based on their circumstances (i.e. budget, source water turbidity, etc.), and help customers make informed decisions about which technology to purchase. The most important factor influencing water treatment technology selection should be source water turbidity level. Within the low turbidity and high turbidity categories, consumers may choose between several treatment options depending on individual circumstances.

6.6.1 Low Turbidity Water Drinkers

The chief treatment options recommended for low turbidity source water drinkers are the *Kosim* pot filter and the siphon filter. The choice between these options seems to depend most importantly on cost and maintenance requirements: the siphon filter is less expensive but requires more extensive maintenance than the *Kosim* filter. However, siphon filter backwashing and pre-filter washing can be performed less frequently with low turbidity water, meaning maintenance requirements are less involved. Therefore, the siphon filter seems to be a better option on these scores. Additional factors that may attract potential customers to the siphon filter are its small size and faster flow rate. (The future version of the siphon filter may also provide a more reliable treatment option than the *Kosim* regarding breakages, but this remains to be seen.) The siphon filter is also a good option for households that already own a safe storage container. For households that do not own such a container, the *Kosim* filter may be an attractive option for its built-in safe storage.

On most counts, the siphon filter would seem to be a better option for low turbidity water than the *Kosim* filter if the siphon filter recontamination issue were resolved. However, both filters and their characteristics should be presented to potential customers.

Chlorination with the locally available Aquatabs product is recommended as an alternative to filter use for households drinking low turbidity water. Although this treatment option is consumable (and expensive), requires a wait for treated water, and produces disinfection byproducts, it may be appropriate for users desiring a low maintenance treatment option.

6.6.2 High Turbidity Water Drinkers

Treatment options for high turbidity water include the *Kosim* filter, the siphon filter, alum plus the siphon filter, and alum plus chlorine.

Siphon Filter versus Ceramic Pot Filter:
Firstly, if the siphon filter recontamination issue were resolved then the siphon filter would be believed to be an equally appropriate or better option than the *Kosim* filter for high turbidity water. The siphon filter is less expensive, features a faster flow rate that is especially significant for high turbidity (which can lower flow rates due to clogging), and includes mechanisms to prevent clogging (i.e. backwashing, pre-filter washing, settling). Educating potential customers of the siphon filter is vital to ensure cleaning mechanisms are well understood and practiced, but the presence of these mechanisms makes the siphon filter a stronger technology than the *Kosim* filter for high turbidity water. One factor in favor of the *Kosim* filter that the siphon filter lacks is integrated safe storage, which may be useful for households that do not already own safe storage containers. However, if the siphon filter were marketed with a safe storage container this issue would be mitigated. Another factor in favor of the *Kosim* filter is that maintenance of this filter is easier and more intuitive than that of the siphon filter.

Alum plus Chlorine:
The alum plus chlorine option requires the least maintenance of the treatment options for highly turbid water. This simplicity may be the most important option for some customers. The chlorine residual offered by this option also means that safe storage is less crucial (though still important), again making the treatment process more care-free. However, alum plus chlorine is relatively expensive long-term, requires multiple purchases and a reliable supply chain for long-term use, and creates disinfection byproducts. Customers will need to weigh these factors.

Siphon Filter versus Alum plus Chlorine:
In comparison to alum plus chlorine, the siphon filter requires more maintenance, which may deter users. If customers drinking highly turbid water do not diligently maintain the filter, the ceramic element may wear out rapidly, making the filter inappropriate. However, if the filter is well-maintained it may provide a more permanent and cost-effective option than alum plus chlorine. Additionally, the siphon filter does not create disinfection byproducts. PHW should caution potential customers of the siphon filter that proper maintenance is crucial for long-term filter use, and should encourage filter use with alum to lengthen filter life.

Alum plus Siphon Filter:
The alum plus siphon filter option is the most maintenance-heavy of the options for highly turbid water. However, use of alum is predicted to make siphon filter maintenance (i.e. backwashing, pre-filter washing) less intensive and siphon filter life longer. The alum plus siphon filter option is comparable to the alum plus chlorine option: alum is used for turbidity removal in both options, and chlorine/the siphon filter is used for disinfection. Chlorine and the siphon filter both have draw-backs in this context: whereas chlorine creates disinfection byproducts, the siphon filter requires maintenance practices.

Both options require multiple purchases of alum (chlorine also needs to be purchased regularly). Customers are not expected to purchase the siphon filter simply to avoid disinfection byproducts, as this is not known to be an issue in Northern Ghana. Therefore, alum plus chlorine seems to offer a better option than alum plus the siphon filter for highly turbid water. However, some customers may desire a more permanent treatment device, and in this case the siphon filter would be recommended on the conditions that the recontamination issue were resolved and that users diligently maintained the filter. Furthermore, the additional regular purchase of alum may not deter some users from the alum plus siphon filter option, as this option offers longer life of a permanent component of treatment, which may be desirable.

The most appropriate option for users with highly turbid water in Northern Ghana seems to be alum plus chlorine for its simplicity of use and for the familiarity and availability of alum. However, the siphon filter may offer an attractive treatment device, and could be effective for users who diligently maintained the filter (if the post-filtration recontamination issue were resolved). The addition of alum is anticipated to make the siphon filter easier to maintain and longer lasting, but might entail too much effort or cost for some users. PHW should discuss these options with potential customers in order to encourage the most appropriate treatment option for each household.

References

"American Berkefeld gravity drip water filter." Ecosystems International. 4 Apr 2009 <http://ecosystemsintl.net/waterfiltershop/pc/viewPrd.asp?idproduct=280>.

"At a glance: Ghana" UNICEFhttp://www.unicef.org/infobycountry/ghana_ statistics.html Accessed 10/15/2008

Ansah, Ernest. "The Pure Home Water Project (PHW) Ghana" Microsoft PowerPoint. Presentation to 1.782 class, Fall, 2006

Bershteyn, A.; Hewlett, S.; Myerson, J.; Ng, S. *Water Disinfection in Ceramic Filters Impregnated with Colloidal Silver*. Department of Materials Science and Engineering, MIT, 2005. http://web.mit.edu/3.042/team4/

Boezeman, Greetje, Louis Pierre Geerinckx, Gijsbert Koren, Martijn van Loon, and Onno Sminia. "Tanzaniaqua: Water Filter for Tanzania." (2008).

Brown, Joe, and Mark Sobsey. "Independent Appraisal of Ceramic Water Filtration Interventions in Cambodia", Report Submitted to UNICEF. (2006).

Brown, Joe, Mark Sobsey, and Dana Loomis. "Local Drinking Water Filters Reduce Diarrheal Disease in Cambodia: A Randomized,." The American Journal of Tropical Medicine and Hygiene. 79 (2008): 394–400.

Brown, Joseph Mark. "Effectiveness of Ceramic Filtraiton for Drinking Water Treatment in Cambodia." University of North Carolina at Chapel Hill Dissertation (2007).

"The Candle." Doulton USA. 4 Apr 2009 <http://doultonusa.com/HTML%20pages/how%20it%20works.htm>.

The Carter Center, http://www.cartercenter.org/healthprograms/ Guinea Worm Wrap Up #182, July 7, 2008

CDC, 2009. Guinea Worm Wrap-Up #187, USA Department of Human Health and Services, Public Health Service Centers for Disease Control and Prevention (CDC), WHO Collaborating Center for Research, Training and Eradication of Dracunculiasis, March 2, 2009.

Central Intelligence Agency (CIA). (2008, 20 November). "CIA - The World Factbook - Ghana." <https://www.cia.gov/cia/publications/factbook/geos/gh.html>.Accessed 1 December 2008.

Clesceri, Lenore S., Arnold E. Greenberg, and Andrew D. Eaton. Standard Methods for the Examination of Water and Wastewater. 20th ed. Washington, DC: American Public Health Association, 1998.

"Diatomite Statistics and Information." USGS. U.S. Geological Survey. 4 Apr 2009 <http://minerals.usgs.gov/minerals/pubs/commodity/diatomite/>.

du Preez, Martella, Ronán M. Conroy, James A. Wright, Sibonginkosi Moyo, Natasha Potgieter, and Stephen W. Gundry. "Short Report: Use of Ceramic Water Filtration in the Prevention of Diarrheal Disease:." The American Journal of Tropical Medicine and Hygiene. 79(2008): 696–701.

Franz, Amber. "A Performance Study of Ceramic Candle Filters in Kenya Including Tests for Coliflage Removal." Massachusetts Institute of Technology Master of Engineering Thesis (2005).

Glacier: Hot and Cold Mineral Dispensers and Water Purifiers. 4 Apr 2009 <http://www.purifiers.co.za/images/Stainless-steel-home-unitbi.jpg>.

Green, V. “Household Water Treatment and Safe Storage Options for Northern Region, Ghana: Consumer Preference and Relative Cost.” Master of Engineering Thesis. Department of Civil and Environmental Engineering. Massachusetts Institute of Technology. June 2008.

Guidelines for Drinking-Water Quality. 3rd. Geneva: World Health Organization, 2006.

Holtslag, Henk (Personal communication, October 2008-May 2009)

“How It Works.” SRV Pty Ltd. 3 May 2009 <http://www.srvba.com.au/Filters/how_it_works.htm>.

“Instructions of Use.” Basic Water Needs Foundation. (2008).

Lantagne, Daniele S.. “Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter: Intrinsic Effectiveness.” (2001).

Lantagne, Daniele S.. “Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter: Field Investigations.” (2001).

Metcalf, Robert. “The Portable Microbiology Laboratory: Revolutionizing Point Source Water Testing in Africa.” PowerPoint presentation (2006). California State University, Sacramento.

Mucott, S., V. Green, A. Swanton, C. Fitzpatrick, 2008. Household Water Treatment and Safe Storage – Consumer Preference and Technology Assessments in Ghana, Massachusetts Institute of Technology and Pure Home Water, Ghana, June 15 2008.

Peletz, R., S. Johnson, J. Bering, S. Murcott. “Health Impact and User Perceptions of Pure Home Water’s *Kosim* Ceramic Filter in Northern Region Ghana .” PowerPoint presentation (2007). Massachusetts Institute of Technology.

Pope, Misty L., Michelle Bussen, Mary Ann Feige,3 Lois Shadix, Sharon Gonder, Crystal Rodgers, Yildiz Chambers, Jessica Pulz, Ken Miller, Kevin Connell, and Jon Standridge. “Assessment of the Effects of Holding Time and Temperature on *Escherichia coli* Densities in Surface Water Samples.” APPLIED AND ENVIRONMENTAL MICROBIOLOGY 69(2003): 6201–6207.

“Siphon Filter Fact Sheet.” Basic Water Needs Foundation. (2008).

“The Siphon Filter.” PowerPoint presentation given by Connect International at the International Symposium on Household Water Management. Accra, Ghana. June 2008.

Stevenson, Matthew. “Monitoring Effective Use of Household Water Treatment and Safe Storage Technologies in Ethiopia and Ghana.” Massachusetts Institute of Technology Master of Engineering Thesis (2008).

Swanton, Andrew. “Evaluation of the Complementary Use of the Ceramic (*Kosim*) Filter and Aquatabs in Northern Region, Ghana.” Master of Engineering Thesis. Department of Civil and Environmental Engineering. Massachusetts Institute of Technology. June 2008.

Tamijesselvan, D.. “I. Drobot.” Bactericidal effect of silver release from ceramic filters. 2008. EMS Lab.

United Nations (UN), 2008a. End Poverty 2015 - Millennium Development Goals - Make It Happen, http://www.un.org/millenniumgoals/, accessed December 1 2008.

United Nations (UN), 2008b. The Millennium Development Goals Report 2008.

van der Ven, Klaas. “The Tulip Water Filter.” Basic Water Needs Foundation. (2008).

van der Ven, Klaas. (Personal communication, October 2008-May 2009)

VanCalcar, J. "Collection and Representation of GIS Data to Aid household Water Treatment and Safe Storage Technology Implementation in the Northern Region of Ghana."Master of Engineer Thesis. Department of Civil and Environmental Engineering. Massachusetts Institute of Technology. June 2006.

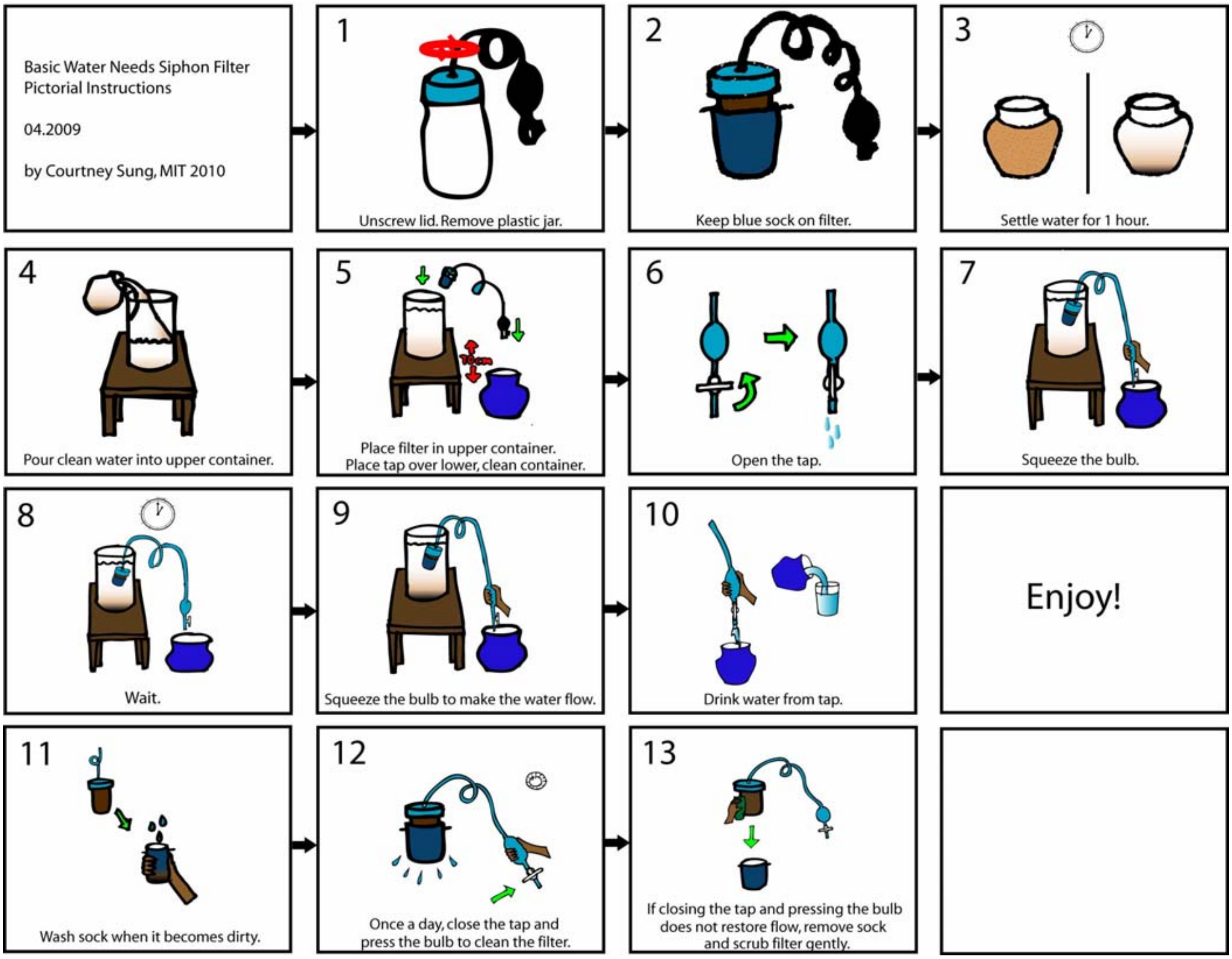
World Health Organization, (1997) Guidelines for Drinking Water Quality, Vol. III, Surveillance and Control of Community Supplies. 2nd Ed. Geneva: WHO.

World Health Organization, *Guidelines for Drinking-Water Quality*. 3rd. Geneva, Switzerland: WHO Press, 2006.

World Health Organisation and UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP), 2008. Progress on Drinking Water and Sanitation, Special Focus on Sanitation.

Wubbels, G. H., I. Duran, and P. Willemse. "Removal Efficiency of Silver Impregnated Ceramic Filters: A Study of the Removal of Pathogenic Bacteria.." Waterlaboratorium Noord. (2008).

Appendix A: Siphon Filter Pictorial Guide



Appendix B: Siphon Filter Distribution Sheet

TULIP FILTER DISTRIBUTION SHEET

FILTER IDENTIFICATION

Filter Number: #01

Compound Number: [redacted]

Community Name: Shishegu

Household Name: [redacted] (Husbands' last name)

Beneficiary Name: [redacted] (Wife's full name)

Beneficiary Address:

GPS Coordinates: NORTH [redacted] WEST/EAST [redacted]

WATER SOURCE

☐ stream ☐ river ☑ dam ☐ pond ☐ lake ☐ spring

☐ borehole ☐ hand dug well (protected) ☐ hand dug well (unprotected) ☑ pipe ☐ other:

PERSON(s) FETCHING WATER IN HOUSEHOLD

☑ woman ☐ child ☐ man

PERSON(s) CONTROLLING FILTERED WATER IN HOUSEHOLD

☑ woman ☐ child ☐ man

LOCATION OF TULIP FILTER IN HOUSEHOLD

☐ room ☑ veranda ☐ kitchen ☐ other:

AVAILABILITY FOR MONITORING & EVALUATION

6:00 am to 9:00 am

BENEFICIARY SIGNATURE OR THUMBPRINT	PHW FIELD STAFF SIGNATURE
[redacted]	(signature)
NAME: [redacted]	NAME: Ibrahim Shakool
DATE: 15/12/08	DATE: 15/12/08

Appendix C: Effective Use Survey

Siphon Filter Effective Use Brief

Hello, my name is Sara Ziff and I am from the Massachusetts Institute of Technology in the United States. I am conducting a household survey on the siphon filter for use in my thesis for the Master of Engineering program at MIT. I would like to talk with a head of your household for about 30 minutes. I will ask you questions about your use of the siphon filter, and will observe how you use the filter in your home. Participation is voluntary; you may decline to answer any or all of the questions and you may end the questionnaire early if you wish. At the end of the survey we would also like to collect a water sample to test the water quality. We will inform you of these results. All personal information you convey will be kept confidential. Do you understand? Are you willing to participate?

Yes		If yes, do you have any questions or may we begin the survey?
No		If no, thank you and we will end our questions here.

Name of Subject ________________________________

Signature of Subject ________________________________ Date ____________

Signature of Investigator ______________________ Date _________

Community:	
Interviewee Name:	
Household/Code:	
Date and Time:	First: Second:
GPS Coordinates:	______________ ______________
Current Water Type:	Pipe Borehole Dam (dugout) Other:
Notes:	

Instructions: For each observation, fill in Yes, No, or place a line through non-applicable observations.

Monitoring Observations		**Checklist** (Yes/No/---)	
Observations	1. Proper placement is witnessed, including:		
	1.1. Upper water container raised to table height or higher		
	1.2. Lower water container is at least 30 cm (1 foot) off the ground.		
	1.3. Both water containers sit level on stable bases large enough to accommodate them.		
	2. Located out of direct sunlight?		
	3. Located out of reach of young children and animals?		

	4. Filter and water containers are clean with no visible leaks or cracks.		
	5. Water level of upper water container is observed to be: < 1 liter 1-2 liters > 2 liters		
	6. The filter is in the upper water container and is currently being used?		
	7. Plastic cover is off of filter when in use?		
	8. Cloth filter is placed around ceramic element?		
Monitoring Questions	9. (If turbid) Do you settle your water in another container for an hour before filtering?		
	10. Do you remember how to backwash?		
	11. (Second visit) Have you backwashed since my last visit? How many times?		
	12. Do you remember when to scrub the filter?		
	13. Is the scrub pad producible and clean?		
	14. Have you cleaned the cloth filter? How frequently?		
	15. Is there a clean cup associated with the filter?		
	16. Is lower container cleaned regularly?		

Additional Questions:

Is the filter easy to use?

What is difficult about the filter?

Do you like the filter?

Do you think the filtered water is cleaner than the source water?

Do you think your source drinking water needs to be treated?

Do you use the filter for purposes other than drinking?

How many people use the filter? Is there enough water for everyone from this filter?

Do you use the filter every day?

Notes:

Appendix D: Water Quality Results

Total Coliform Data

			Colilert ®	3M™ Petrifilm™	
Water Type	**Household**	**Description**	**Positive (+) or Negative (-)**	**Total Colonies**	**Total Coliform (CFU per 100 ml)**
Pipe	91	Filtered	-	0	9
Pipe	91	Unfiltered	+	2	200
Pipe	162	Filtered	-	0	9
Pipe	162	Unfiltered	+	42	4200
Pipe	164	Filtered	-	0	9
Pipe	164	Unfiltered	+	115	11500
Pipe	164	Filtered	-	0	9
Pipe	164	Unfiltered	+	95	9500
Pipe	463	Filtered	+	0	99
Pipe	463	Unfiltered	+	**2**	200
Pipe	463	Filtered	+	0	99
Pipe	463	Unfiltered	-	0	9
Pipe	9	Filtered	-	0	9
Pipe	9	Unfiltered	+	138	13800
Pipe	67	Filtered	-	0	9
Pipe	67	Unfiltered	+	29	2900
Pipe	67	Filtered	-	0	9
Pipe	67	Unfiltered	+	0	99
Pipe	308	Filtered	-	0	9
Pipe	308	Unfiltered	+	0	99
Pipe	308	Filtered	-	0	9
Pipe	308	Unfiltered	-	0	9
Pipe	546	Filtered	+	1	100
Pipe	546	Unfiltered	+	0	99
Pipe	546	Filtered	-	0	9
Pipe	546	Unfiltered	-	0	9
Pipe	28	Filtered	+	0	99
Pipe	28	Unfiltered	+	9	900
Pipe	28	Filtered	-	0	9
Pipe	28	Unfiltered	+	6	600
Pipe	4	Filtered	+	0	99
Pipe	4	Unfiltered	+	0	99
Pipe	4	Filtered	+	0	99
Pipe	4	Unfiltered	+	187	18700
Pipe	219	Filtered	-	0	9
Pipe	219	Unfiltered	-	0	9
Pipe	219	Filtered	-	0	9
Pipe	219	Unfiltered	+	1	100
Pipe	104	Filtered	-	0	9
Pipe	104	Unfiltered	+	43	4300

			Colilert ®	3M™ Petrifilm™	
Water Type	**Household**	**Description**	**Positive (+) or Negative (-)**	**Total Colonies**	**Total Coliform (CFU per 100 ml)**
Pipe	104	Filtered	-	0	9
Pipe	104	Unfiltered	+	11	1100
Pipe	6	Filtered	-	0	9
Pipe	6	Unfiltered	-	0	9
Pipe	6	Filtered	-	0	9
Pipe	6	Unfiltered	-	0	9
Pipe	24	Filtered	-	0	9
Pipe	24	Unfiltered	-	0	9
Borehole	S1	Filtered	-	0	9
Borehole	S1	Unfiltered	-	0	9
Borehole	S1	Filtered	-	0	9
Borehole	S1	Unfiltered	-	0	9
Borehole	38	Filtered	+	0	99
Borehole	38	Unfiltered	+	63	6300
Well	24	Filtered	-	0	9
Well	24	Unfiltered	-	0	9
Well	23	Filtered	-	0	9
Well	23	Unfiltered	+	0	99
Well	23	Filtered	-	0	9
Well	23	Unfiltered	+	1	100
Well	58	Filtered	+	4	400
Well	58	Unfiltered	+	27	2700
Dam	91	Filtered	+	0	99
Dam	91	Unfiltered	+	61	6100
Dam	162	Filtered	-	0	9
Dam	162	Unfiltered	+	8	800
Dam	9	Filtered	-	0	9
Dam	9	Unfiltered	+	37	3700
Dam	10	Filtered	-	0	9
Dam	10	Unfiltered	+	44	4400
Dam	10	Filtered	+	0	99
Dam	10	Unfiltered	+	82	8200
Dam	21	Filtered	+	0	99
Dam	21	Unfiltered	+	10	1000
Dam	21	Filtered	+	0	99
Dam	21	Unfiltered	+	300	30000
Dam	38	Filtered	+	80	8000
Dam	38	Unfiltered	+	200	20000
Dam	51	Filtered	+	8	800
Dam	51	Unfiltered	+	20	2000
Dam	51	Filtered	+	9	900
Dam	51	Unfiltered	+	27	2700
Dam	55	Filtered	+	78	7800

			Colilert ®	3M™ Petrifilm™	
Water Type	Household	Description	Positive (+) or Negative (-)	Total Colonies	Total Coliform (CFU per 100 ml)
Dam	55	Unfiltered	+	6	600
Dam	55	Filtered	+	270	27000
Dam	55	Unfiltered	+	14	1400
Dam	58	Filtered	+	37	3700
Dam	58	Unfiltered	+	94	9400
Dam	59	Filtered	+	0	99
Dam	59	Unfiltered	+	30	3000
Dam	59	Filtered	+	0	99
Dam	59	Unfiltered	+	53	5300
Dam	1912	Filtered	-	0	9
Dam	1912	Unfiltered	+	22	2200
Dam	1912	Filtered	+	13	1300
Dam	1912	Unfiltered	+	4	400

E. coli Data

			Colilert ®	3M™ Petrifilm™	
Water Type	**Household**	**Description**	**Positive (+) or Negative (-)**	**Blue Colonies**	***E. coli* (CFU per 100 ml)**
Pipe	91	Filtered	-	0	9
Pipe	91	Unfiltered	-	0	9
Pipe	162	Filtered	-	0	9
Pipe	162	Unfiltered	+	1	100
Pipe	164	Filtered	-	0	9
Pipe	164	Unfiltered	+	11	1100
Pipe	164	Filtered	-	0	9
Pipe	164	Unfiltered	-	0	9
Pipe	463	Filtered	-	0	9
Pipe	463	Unfiltered	-	3	300
Pipe	463	Filtered	-	0	9
Pipe	463	Unfiltered	-	0	9
Pipe	9	Filtered	-	0	9
Pipe	9	Unfiltered	+	15	1500
Pipe	67	Filtered	-	0	9
Pipe	67	Unfiltered	+	0	99
Pipe	67	Filtered	-	0	9
Pipe	67	Unfiltered	-	0	9
Pipe	308	Filtered	-	0	9
Pipe	308	Unfiltered	-	0	9
Pipe	308	Filtered	-	0	9
Pipe	308	Unfiltered	-	0	9
Pipe	546	Filtered	-	0	9
Pipe	546	Unfiltered	-	0	9
Pipe	546	Filtered	-	0	9
Pipe	546	Unfiltered	-	0	9
Pipe	28	Filtered	-	0	9
Pipe	28	Unfiltered	-	0	9
Pipe	28	Filtered	-	0	9
Pipe	28	Unfiltered	+	0	99
Pipe	4	Filtered	-	0	9
Pipe	4	Unfiltered	-	0	9
Pipe	4	Filtered	-	0	9
Pipe	4	Unfiltered	+	1	100
Pipe	219	Filtered	-	0	9
Pipe	219	Unfiltered	-	0	9
Pipe	219	Filtered	-	0	9
Pipe	219	Unfiltered	-	0	9
Pipe	104	Filtered	-	0	9
Pipe	104	Unfiltered	+	6	600

			Colilert ®	3M™ Petrifilm™	
Water Type	**Household**	**Description**	**Positive (+) or Negative (-)**	**Blue Colonies**	***E. coli*** **(CFU per 100 ml)**
Pipe	104	Filtered	-	0	9
Pipe	104	Unfiltered	+	0	99
Pipe	6	Filtered	-	0	9
Pipe	6	Unfiltered	-	0	9
Pipe	6	Filtered	-	0	9
Pipe	6	Unfiltered	-	0	9
Pipe	24	Filtered	-	0	9
Pipe	24	Unfiltered	-	0	9
Borehole	S1	Filtered	-	0	9
Borehole	S1	Unfiltered	-	0	9
Borehole	S1	Filtered	-	0	9
Borehole	S1	Unfiltered	-	0	9
Borehole	38	Filtered	-	0	9
Borehole	38	Unfiltered	+	5	500
Well	24	Filtered	-	0	9
Well	24	Unfiltered	-	0	9
Well	23	Filtered	-	0	9
Well	23	Unfiltered	-	0	9
Well	23	Filtered	-	0	9
Well	23	Unfiltered	-	0	9
Well	58	Filtered	+	0	99
Well	58	Unfiltered	+	0	99
Dam	91	Filtered	-	0	9
Dam	91	Unfiltered	+	4	400
Dam	162	Filtered	-	0	9
Dam	162	Unfiltered	+	3	300
Dam	9	Filtered	-	0	9
Dam	9	Unfiltered	+	0	99
Dam	10	Filtered	-	0	9
Dam	10	Unfiltered	+	2	200
Dam	10	Filtered	-	0	9
Dam	10	Unfiltered	+	1	100
Dam	21	Filtered	-	0	9
Dam	21	Unfiltered	+	0	99
Dam	21	Filtered	-	0	9
Dam	21	Unfiltered	+	0	99
Dam	38	Filtered	-	0	9
Dam	38	Unfiltered	+	0	99
Dam	51	Filtered	-	0	9
Dam	51	Unfiltered	+	0	99
Dam	51	Filtered	-	0	9
Dam	51	Unfiltered	+	2	200
Dam	55	Filtered	+	8	800

			Colilert ®	3M™ Petrifilm™	
Water Type	**Household**	**Description**	**Positive (+) or Negative (-)**	**Blue Colonies**	***E. coli*** **(CFU per 100 ml)**
Dam	55	Unfiltered	+	52	5200
Dam	55	Filtered	+	0	99
Dam	55	Unfiltered	-	0	9
Dam	58	Filtered	-	0	9
Dam	58	Unfiltered	-	0	9
Dam	59	Filtered	+	4	400
Dam	59	Unfiltered	-	0	9
Dam	59	Filtered	+	2	200
Dam	59	Unfiltered	-	0	9
Dam	1912	Filtered	+	2	200
Dam	1912	Unfiltered	-	0	9
Dam	1912	Filtered	+	0	99
Dam	1912	Unfiltered	+	52	5200

Turbidity Data

Water Type	Household	Description	Turbidity (NTU)
Pipe	91	Filtered	30.3
Pipe	91	Unfiltered	6.16
Pipe	162	Filtered	10.0
Pipe	162	Unfiltered	10.2
Pipe	164	Filtered	31.9
Pipe	164	Unfiltered	12.5
Pipe	164	Filtered	5.77
Pipe	164	Unfiltered	2.82
Pipe	463	Filtered	4.9
Pipe	463	Unfiltered	2.2
Pipe	463	Filtered	4.36
Pipe	463	Unfiltered	9.45
Pipe	9	Filtered	4.4
Pipe	9	Unfiltered	9.8
Pipe	67	Filtered	31.1
Pipe	67	Unfiltered	16.1
Pipe	67	Filtered	34.3
Pipe	67	Unfiltered	1.22
Pipe	308	Filtered	12.1
Pipe	308	Unfiltered	5.3
Pipe	308	Filtered	6.81
Pipe	308	Unfiltered	6.01
Pipe	546	Filtered	6.9
Pipe	546	Unfiltered	2.6
Pipe	546	Filtered	36.8
Pipe	546	Unfiltered	4.47
Pipe	28	Filtered	39.9
Pipe	28	Unfiltered	3.62
Pipe	28	Filtered	9.36
Pipe	28	Unfiltered	2.32
Pipe	4	Filtered	2.16
Pipe	4	Unfiltered	3.85
Pipe	4	Filtered	10.3
Pipe	4	Unfiltered	2.7
Pipe	219	Filtered	4.7
Pipe	219	Unfiltered	4.8
Pipe	219	Filtered	5.6
Pipe	219	Unfiltered	5.5
Pipe	104	Filtered	6.68
Pipe	104	Unfiltered	4.09

Water Type	Household	Description	Turbidity (NTU)
Pipe	104	Filtered	3.55
Pipe	104	Unfiltered	3.73
Pipe	6	Filtered	5.6
Pipe	6	Unfiltered	5.6
Pipe	6	Filtered	7.27
Pipe	6	Unfiltered	5.79
Pipe	24	Filtered	6.9
Pipe	24	Unfiltered	6.6
Borehole	S1	Filtered	44.5
Borehole	S1	Unfiltered	2.8
Borehole	S1	Filtered	7.19
Borehole	S1	Unfiltered	2.16
Borehole	38	Filtered	111
Borehole	38	Unfiltered	55.7
Well	24	Filtered	5.59
Well	24	Unfiltered	2.68
Well	23	Filtered	2.8
Well	23	Unfiltered	3.5
Well	23	Filtered	7.99
Well	23	Unfiltered	2.16
Well	58	Filtered	6.93
Well	58	Unfiltered	41.5
Dam	91	Filtered	47.8
Dam	91	Unfiltered	44.0
Dam	162	Filtered	9.79
Dam	162	Unfiltered	7.74
Dam	9	Filtered	5.29
Dam	9	Unfiltered	16.7
Dam	10	Filtered	52.1
Dam	10	Unfiltered	101
Dam	10	Filtered	23.3
Dam	10	Unfiltered	102
Dam	21	Filtered	7.67
Dam	21	Unfiltered	97.7
Dam	21	Filtered	4.69
Dam	21	Unfiltered	103
Dam	38	Filtered	38.8
Dam	38	Unfiltered	155
Dam	51	Filtered	7.07
Dam	51	Unfiltered	98.7
Dam	51	Filtered	4.28
Dam	51	Unfiltered	100
Dam	55	Filtered	11.7
Dam	55	Unfiltered	111
Dam	55	Filtered	14.2

Water Type	Household	Description	Turbidity (NTU)
Dam	55	Unfiltered	151
Dam	58	Filtered	50.7
Dam	58	Unfiltered	119
Dam	59	Filtered	44.8
Dam	59	Unfiltered	231
Dam	59	Filtered	10.1
Dam	59	Unfiltered	160
Dam	1912	Filtered	32.1
Dam	1912	Unfiltered	120
Dam	1912	Filtered	9.56
Dam	1912	Unfiltered	82.4

Appendix E: MIT D-Lab Brong Ahafo Study

As a supplement to the field study conducted for this thesis project in the Northern Region, a team of MIT students that were enrolled in the course D-Lab I: Introduction to Development studied ten (10) siphon filters in the village of New Longoro in the Brong Ahafo Region of Ghana, also during January 2009.

These students, including Courtney Sung and Kofi Taha, conducted water quality tests (primarily membrane filtration[20] and 3M Petrifilm tests) on borehole and local river water, which were the local drinking water sources, filtered through the siphon filters and determined that they were effective at reducing coliform counts for the water resources in this area.

The MIT D-Lab team also consulted with the local Water Committee, Peace Corps volunteer and Methodist pastor to determine the best method of distribution and testing within the village. The MIT team opted to leave one (1) filter at the Junior Secondary School to facilitate education regarding hygiene and water treatment with the youth (led by the Peace Corps volunteer) and two (2) with families that were highly regarded and involved with the community. The MIT team conducted a few run-throughs with these participants to determine proficiency with usage of the filter, and left instructions with the Peace Corps volunteer and pastor (the MIT D-Lab community partners) in case of misunderstanding. The community partners agreed to go back to visit these families regularly to monitor their usage of the filter; one of the women the MIT team gave a filter to expressed interest in teaching some local rural farmers how to use the siphon filter. The community partners will distribute the remaining seven (7) filters as they see fit.

[20] The membrane filtration test is a standard method of estimating coliform levels in water. The method involves first passing a 100 ml water sample through a 0.45 μm membrane that collects any bacteria in the sample, and then using a culture medium that is selective for coliform growth to grow coliform colonies under incubation. Colonies are counted to determine coliform levels.