Monitoring and Evaluation of the Ceramic Hemispheric Filter in Northern Ghanaian Households

by

Kristine M. Cheng

B.S. in Civil Engineering
New Jersey Institute of Technology, 2012

Submitted to the Department of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of

Master of Engineering in Civil and Environmental Engineering
at the
Massachusetts Institute of Technology
June 2013

© 2013 Massachusetts Institute of Technology. All rights reserved.

Signature of Author: ____
Department of Civil and Environmental Engineering
May 13, 2013

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

Accepted by: ____
Heidi M. Nepf
Chair, Departmental Committee for Graduate Students

Page intentionally left blank.

Monitoring and Evaluation of the Ceramic Hemispheric Filter in Northern Ghanaian Households

by

Kristine M. Cheng

Submitted to the Department of Civil and Environmental Engineering on May 13, 2013, in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Civil and Environmental Engineering

ABSTRACT

The village of Yipelgu in the Northern Region of Ghana was the recipient of a 1,000-ceramic hemispheric water filter distribution, which was supplied by Pure Home Water (PHW) and funded by UNICEF-Ghana. The distribution to female heads of households began in November 2012, and approximately 700 ceramic hemispheric filters were disseminated by January 2013 when this research was conducted. This large-scale distribution provided the first opportunity to monitor and evaluate the performance of PHW's ceramic hemispheric filter design, branded as the AfriClay filter, in the field rather than during the factory quality control operations. Monitoring and evaluation was based on surveys measuring Correct Use and water quality tests. Correct Use is the first component of the "3C's", which denote Correct, Consistent, and Continuous Use. A user practicing the "3C's" can realize the full benefits of this and other household water treatment and safe storage (HWTS) products.

The Correct Use survey was administered to a total of 85 beneficiary households in Yipelgu. Pertinent factors, such as filter assembly, treatment, safe storage, and maintenance, related to Correct Use were addressed in the survey. The variables included in the survey were hypothesized to inform the filter performance level. Stored untreated and filtered paired samples were also collected from each survey respondent's filter. IDEXX Quanti-Tray/2000® and hydrogen sulfide (H_2S) bacteria MPN tests were conducted to measure the water quality parameters of total coliform/*E. coli* and H_2S bacteria respectively. Turbidity was also measured. Water quality tests served as an objective measure for HWTS adoption and Correct Use.

The AfriClay filter exhibited a wide range of performance but generally achieved 99% total coliform (TC), 98% *E. coli*, and 80% turbidity reductions (geometrically averaged). In order to explain this observed performance variability, water quality and Correct Use survey data were analyzed. The variables of "fill frequency per day" and "duration of turbid water settling" were found to be statistically significant in possibly influencing the filter performance level from the observed data.

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

Page intentionally left blank.

ACKNOWLEDGMENTS

I would like to thank my mother, father, and sister for their endless support and encouragement. I am blessed and grateful to have a loving family who is a constant source of motivation.

Susan Murcott – thank you for your advice, insight, and understanding. You are an inspiration to your students.

Ezra Haber Glenn – I am indebted to your encouragement and guidance in data analysis, without which this thesis would not be possible.

To Shengkun Yang, Deborah Vacs Renwick, Amelia Tepper Servi, and Abel Manangi, I could not have had a more wonderful time in Ghana without all of you. Thank you for your frequent help in the laboratory and company in the field, as well as your patience in showing me the ropes at the PHW factory. But most importantly, thank you for your friendship.

I owe many thanks and appreciation to Abdul-Karim Alale, an incredible guide, translator, and dear friend.

Finally, my gratitude extends to the support of MIT Public Service Center and the M.Eng program.

This thesis is dedicated to my grandmother, Maria J. de Lara. I miss you dearly and hope to make you proud.

Page intentionally left blank.

ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
BSF	BioSand Filter
CPF	Ceramic Pot Filter
E. coli	Escherichia Coli
H_2S	Hydrogen Sulfide
HWTS	Household Water Treatment and Safe Storage
JMP	Joint Monitoring Program
LRV	Log Removal Value
M&E	Monitoring and Evaluation
M.Eng	Master of Engineering
MDG	Millennium Development Goal
MPN	Most Probable Number
NTU	Nephelometric Turbidity Units
P/A	Presence/Absence
PHW	Pure Home Water
QT	Quanti-Tray/2000®
TC	Total Coliform
UNICEF	United Nations Children's Fund
US EPA	United States Environmental Protection Agency
USAID	United States Agency for International Development
WASH	Water, Sanitation, and Hygiene
WHO	World Health Organization

Table of Contents

Equations

Figures

Tables

1. Introduction

Pure Home Water (PHW), a social enterprise and ceramic water filter manufacturer and distributor, disseminated its AfriClay ceramic hemispheric filter to the village of Yipelgu in Northern Ghana from November 2012 to February 2013. This is the first large-scale distribution of hemispheric filters produced at the PHW factory. This distribution was funded by UNICEF-Ghana. The village of Yipelgu is approximately 20 miles west of Tamale. UNICEF-Ghana selected Yipelgu due to its reputation for extremely turbid water sources, derived from mostly earthen dams, locally called "dugouts." The total population of Yipelgu is not known, but there are thought to be approximately 1,000 households. Upon distribution of the filters, training and installation was provided by the local government together with PHW staff.
PHW's AfriClay ceramic hemispheric filter design has been produced since the beginning of 2012 at the organization's factory in Taha, Ghana, which is about 5 miles east of Tamale Center. The Correct Use survey, designed by the author, is the first monitoring and evaluation (M&E) instrument to assess PHW's new hemispheric filter design and implementation in a household setting. The research and analysis presented in this thesis contribute to one of Pure Home Water (PHW)'s goals, which is to assist in supplying safe and affordable drinking water, sanitation, and hygiene (WASH) in Northern Ghana.

1.1. Republic of Ghana

The Republic of Ghana is a West African nation located along the coast of the Gulf of Guinea (**Figure 1-1**), with a total area of 92,098 mi^2 (238,535 km^2). As of 2012, Ghana has an estimated population of 25.2 million people (Encyclopedia Britannica, 2013). The country is made up of 10 regions: Upper West, Upper East, Northern, Brong-Ahafo, Volta, Ashanti, Eastern, Greater Accra, Central, and Western Regions. The author's research and Pure Home Water (PHW) operations take place in the Northern Region, where Tamale is the regional capital.

The Northern Region experiences intense seasonal climate with a dry and rainy season. The hot, dry season extends from December to March, while the rainy season lasts from May to November. The highest temperatures occur in the dry season at 81 – 86°F (27 – 30°C), and lowest temperatures of 77 – 81°F (25 – 27°C), during the rainy season. The nature of this seasonality is due to a shift in predominate wind direction from south-westerly to north-easterly winds transporting dry air, dust, and relatively little precipitation during the dry months (McSweeney, New, & Lizcano, 2008). The author conducted her research during the dry season.

Figure 1-1: Regional map of Ghana (Maps of the World, 2013).

Ghana currently holds "on track" status in reaching the United Nation (UN)'s Millennium Development Goal 7, Target C for safe drinking water by 2015. However, the country faces shortages in clean drinking water; especially in the North, where more than half the populace uses unimproved drinking water sources. The village of Yipelgu is located in the Tolon-Kumbungu District, where about 75% of the population uses unimproved sources for drinking water purposes as seen in **Figure 1-2**.

Figure 1-2: Improved and unimproved drinking water sources in Northern Region Districts (VanCalcar, 2006).

Consequently, occurrence of waterborne diseases, such as diarrhea, is extremely high. Diarrhea, which can cause severe dehydration, is a significant contributor to the morbidity and mortality of children under the age of five years old. The Northern Region has the highest rate of diarrhea prevalence in Ghana with 32.5% as reported from the 2008 Demographic and Health Survey (Ghana Statistical Service & Ghana Health Service, 2009). According to Lu (2012), the overall prevalence of diarrhea for individuals that fall under this demographic is 23%, which was determined from 10 Northern Regional communities during her study. There is a great need for improved water management and drinking water treatment options in this region.

1.2. Pure Home Water (PHW) and AfriClay Filter

Pure Home Water (PHW) is a registered non-profit organization based in Tamale, Ghana. PHW has been providing household water treatment and safe storage (HWTS) products and services since its establishment in 2005. The organization has two main goals: (1) provide safe drinking water, sanitation, and hygiene (WASH) in Ghana; and (2) become locally and financially self-sustaining. In order to reach these goals, PHW has researched and developed a porous ceramic pot filter called the AfriClay filter. As mentioned previously, PHW's AfriClay ceramic hemispheric filter design has been produced since the beginning of 2012 at the organization's factory in Taha, Ghana.

These types of filters have defined pore sizes and are painted with a coating of colloidal silver. Clay, water, and a combustible, rice husk, are molded into a hemisphere pot shape that creates the ceramic filtering element. The filtering element has a volumetric capacity of about 10 liters. The purpose of adding a combustible is to create pores when the filtering element is fired in a kiln. This technology is reliant on key mechanisms, some of which include: screening large particles at the filter's surface (mechanical screening), capture of contaminants within the filter cavity walls (adsorption), and bacteria disinfection from colloidal silver (chemical and biological activity). **Figure 1-3** shows Pure Home Water's new ceramic hemispheric design. An important feature of the AfriClay filter system is the built-in safe storage container.

Figure 1-3: PHW's AfriClay filter system.

Table 1-1 summarizes the anticipated reductions of bacteria, viruses, and protozoan parasites by porous ceramic filters. Baseline and maximum reductions listed are established from the accumulation of reported scientific studies (WHO, 2011b). Baseline removals are expected to be achieved in the field by relatively unskilled persons that treat raw water of average and variant quality. Maximum removals can be attained when skilled operators treat water of predictable and steady state quality. Differences in the $\log_{10}$ reduction value (LRV) performance of certain water treatment technologies can be exhibited across different water treatment methods (WHO, 2011b).

Table 1-1: Reductions of bacteria, viruses, and protozoa achieved by porous ceramic and carbon block filtration (WHO, 2011b).

Enteric Pathogen Group	Baseline Removal (LRV)	Maximum Removal (LRV)	Notes
Bacteria	2	6	Varies with pore size, flow rate, filter medium and inclusion of augmentation with silver or other chemical agents
Viruses	1	4	
Protozoa	4	6	

1.3. Distribution Logistics

The initial distribution plan was to disseminate the filter to every household in the village of Yipelgu, to a total of 1000 households, by December 2012. Due to an unexpected delay in constructing a kiln at PHW's factory, approximately 700 filters were ready by December 2012 and distributed to the village by the time the author had began her field work on January 4, 2013. Given that all households would be receiving these filters by the end of the distribution, these 700 filters were not distributed in a systematic manner, but rather on the basis of which households were available at the time of the trainings. As a result there was no record of which households have already received the filter and consequently the whereabouts of a specific filter each stamped with a unique factory number.

During the months of November and December, certain days were scheduled so that government officials, community leaders, and PHW staff were able to coordinate and meet with villagers in order to distribute the filters and hold training sessions. Training sessions were comprised of a community-wide demonstration of assembly, operation, and maintenance (which is monitored via the Correct Use survey), followed by dividing into groups of 10 to assemble the filters, and finally individual installation of the system into each household. Villagers were notified in advance of the distribution days so that a requirement of reaching a specific attendance was met. Otherwise, many would be occupied in working their farms (the most common employment and livelihood) because the distribution happened to coincide with the growing season.

The filters were only distributed to the women of the village. The reasoning behind distributing the filters to only the women is due to their responsibility in caring for children under the age of 5, many of whom have a high incidence of diarrheal disease caused by waterborne pathogens. Due to the manner in which the filters were distributed, on arrival the survey team would find that a given compound may have households with or without filters. It also could be the case that an entire compound has not received filters at all. It should be noted that by February 2013, all compounds in Yipelgu were saturated with filters, but not at the time of this field research.

A compound is a walled complex that encompasses the dwellings of wives and their children, in addition to separate lodgings for the adult male family members (**Figure 1-4**). Most of the villages in Northern Ghana practice polygamy, where a husband has multiple wives. The husband is considered the head of the compound. Each wife has her own round hut with a thatched roof, while the husband or male relative resides in his own larger rectangular-shaped dwelling usually affixed with metal roofing, as can be seen on the right side of **Figure 1-4**. A household defined for the purposes of this research is the unit of one wife, her children, and any immediate family living with her that reside in a discrete dwelling.

Figure 1-4: Depiction of a typical compound in the village of Yipelgu.

1.4. The 3C's: Correct, Consistent, and Continuous Use

It is important for PHW to monitor and evaluate the combination of Correct, Consistent, and Continuous use, referred to as the "3 C's," of the household drinking water treatment and safe storage technology.

- **Correct Use** denotes that the filter is being used properly, according to the training that each user receives before filter sale/distribution and as given in the instructional sticker on each filter and in the Training Manual).
- **Consistent Use** refers to whether the technology is used every day.
- **Continuous Use** relates to whether the filter is used throughout an entire year.

Continuous Use is necessary and essential to the 3C's since some users have wrongly thought that they do not need to use the HWTS technology during the rainy season when cleaner rainwater is more abundant. The implementation of the 3 C's is the latest thinking regarding a successful behavioral training method to sustain safe drinking water consumption. As WHO and UNICEF (2012) reports, “While a growing body of evidence demonstrates that the use of household water treatment and safe storage (HWTS) methods improves the microbial quality of household drinking-water and reduces the burden of diarrheal disease in users, there is also increasing evidence that inconsistent and/or incorrect use may be the major challenge in realizing the full potential from HWTS. In order to develop effective mechanisms to encourage and sustain correct use of HWTS, there is need to monitor and evaluate uptake” (p. 5).

Individuals must correctly, consistently, and continuously use the appropriate HWTS method in order to attain the full effectiveness of the preventative health intervention. Obtaining an accurate percentage of the population that actually uses the HWTS method to generate safe drinking water gives insight into overcoming challenges related to the 3C’s. Many studies have concluded that less frequent use of HWTS is related to a higher diarrheal disease rate (WHO & UNICEF, 2012). Information gathered through monitoring and evaluating efforts can give a dependable assessment of the technology, which can be used to modify programs, distributions, and training, and maximize the benefits incurred from use.

Less than adequate or incomplete implementation can lead to non-use, inconsistent, or discontinuous use of HWTS. This can occur if beneficiaries did not receive enough training on how to operate the HWTS or using the technology is deemed too cumbersome. It could also be the case that the HWTS technology is culturally or religiously unacceptable (WHO & UNICEF, 2012). Understanding these factors can inform future implementation efforts.

United States Agency for International Development (USAID) published a document entitled *Access and Behavioral Outcome Indicators for Water, Sanitation, and Hygiene* that describes an extensive list of indicators addressing behavioral determinants that may affect the adoption of HWTS methods. Indicators that are related to Correct and Sustained Use, in addition to water quality tests, are listed in **Table 1-2**. USAID’s definition of Sustained Use is the practice of recommended household treatment of drinking water during at least two different measurements separated by a specified time frame using the same study respondents, which can be considered synonymous with what is referred to as Continuous Use in this report. The document notes that the water quality test listed below serves as the definite measure to determine Correct Use.

Table 1-2: Summary of Correct, Sustained, and water quality indicators (USAID, 2010).

Indicator	Question/Request	Answer/Observation
% of households practicing Correct Use of recommended household water treatment technologies	1. May I see your filter? 2. (Based on observation) Is there water in the bottom container?	1. Yes or No 2. Yes or No
% of households practicing Sustained Use of recommended household water treatment technologies	Use the same questions listed above since it a longitudinal study and the focus is on the comparison over time with the same respondents.	Same as above.
% of households with negative test for *E. coli* in drinking water at the point of use	May I take a sample of your drinking water?	Allowed or Not Allowed

Twenty monitoring and evaluation indicators from USAID's Hygiene Improvement Project are expanded in WHO and UNICEF's *A Toolkit for Monitoring and Evaluating Household Water Treatment and Safe Storage Programmes*. These indicators address similar themes of Correct and Consistent Use. A summary of these pertinent indicators along with their associated survey questions and answers/observations are presented in **Table 1-3.**

Table 1-3: Summary of Correct and Consistent Use indicators (WHO & UNICEF, 2012).

Correct Use			Consistent Use		
Indicator	Question/ Request	Answer/ Observation	**Indicator**	Question/ Request	Answer/ Observation
Knowledge of Correct Use	Please describe how to use this method.	Dependent on method.	Frequency of non-use by most vulnerable	1. How often do children in your household drink untreated water? 2. If not always, where do they report drinking untreated water?	1. Always, usually, sometimes, never 2. School, work, religious center, when traveling, in fields (etc.)
Demonstration of Correct Use	Please show me how you use this method.	Dependent on method.			
Demonstration of safe water extraction	Please show me how you usually extract water from your container.	Observe whether hands touch water. Observe if tap is clean.	Consistently treating drinking-water with HWTS	1. Have you ever used the HWTS method? In last month? In last week? Always? 2. When do you not use?	1. Yes or No 2. When there is no money, when there is no time, during the rainy season, during the dry season, never not use, other

WHO and UNICEF (2012) also address water quality indicators, which are objective measures of Correct Use. For the purpose of this study, the applicable water quality indicator description is listed in **Table 1-4**.

Table 1-4: Summary of water quality indicator (WHO & UNICEF, 2012).

Indicator	**Question/Request**	**Answer/Observation**
Households effectively using HWTS method to improve quality of household drinking-water	Can you please provide me a cup of water as you would give to a child? If treated, collect paired untreated sample.	Test stored untreated and treated drinking-water pairs for indicator bacteria, report reduction of bacteria.

To address the issue of how often to collect data in order to determine Correct and/or Consistent Use, WHO and UNICEF (2012) recommend intervals (4 to 6 months) over 2 to 5 years rather than over shorter time periods or in only one instance. Data that is collected over time, also referred to as longitudinal data, can identify trigger points that contribute to increased use or disuse, such as treating water in only the rainy season (perceived microbial risk) or only for a few weeks after harvest (expendable income). The act of surveying can influence HWTS use, i.e. when longitudinal data is collected; an associated lower rate of prevalence of child diarrhea is reported.

The research presented in this thesis focuses on the Correct Use aspect of the 3 C's, based on water quality tests and the survey participant's demonstration and understanding of correct household filter use as identified through household surveys. Correct Use will be the sole focus due to time logistics. Monitoring Correct Use enables rapid behavior change if incorrect use is observed. Revised and future surveys that address the 3C's are proposed in **Appendix A - D,** which incorporates USAID's Correct and Sustained Use indicators, as well as WHO-UNICEF's Correct and Consistent indicators.

Page intentionally left blank.

2. Research Objectives

The goal of this thesis is to monitor and evaluate Pure Home Water's AfriClay ceramic hemispheric filter at the household level in the village of Yipelgu. The distribution at Yipelgu was the first mass distribution of filters manufactured at Pure Home Water's factory. Therefore, the filters assessed during the research period comprise the first set to be monitored and evaluated in the field rather than tested in the factory's quality control operations. In order to accomplish this goal, the following objectives are to: (1) Focus on water quality data as the primary filter performance indicator; (2) Identify behavioral factors from Correct Use surveys that affect filter performance; and (3) Create a baseline and compile recommendations for future distributions/monitoring efforts.

Page intentionally left blank.

3. Literature Review

Globally, unimproved sources are used by an estimated 780 million people for their drinking water needs, while contaminated improved sources are being used by millions more for the same purpose (WHO & UNICEF, 2012). Unsafe drinking water and inadequate sanitation and hygiene contribute to approximately 1.9 million deaths annually, mainly of children under the age of five (WHO, 2013). Household water treatment and safe storage (HWTS) can serve as interim measures to prevent contamination during collection, transport, and domestic, which can decrease the incidence of diarrheal disease in users until safe piped systems are connected to every household (WHO & UNICEF, 2012). HWTS also provide an additional barrier of protection for those whose improved water is not necessarily safe.

Studies have shown that HWTS methods improve drinking water microbial quality and diminish the incidence of waterborne diseases, such as diarrhea (Fewtrell et al., 2005; Clasen et al., 2007; Waddington et al., 2009). However, there is mounting evidence that adherence and/or incorrect use may be the main obstacle to overcome in order to attain the full capabilities of HWTS (WHO & UNICEF, 2012). The study of Enger et. al (2012) about the effectiveness of water treatment against childhood diarrhea contributes to this evidence. Enger et. al (2012) explored the dynamic factors of efficacy, measured by log reduction values (LRVs), and adherence, measured by the frequency of HWTS use through a quantitative microbial risk assessment model (QMRA). In that study, compliance or adherence is defined as," proportion of drinking water treated by a community." Which is not be confused with the definition of compliance, in this thesis, which is the proportion of respondents reporting or exhibiting a Correct Use behavior measured by a survey variable. Enger et. al (2012) concluded that gains from increasing LRVs are directly influenced by adherence. In the case of full adherence, a relationship of decreasing diarrheal incidence with increasing LRVs was exhibited. It was also found that if full adherence is not reached, health benefits decrease even with increasing LRVs.

Monitoring and evaluation of HWTS intervention is necessary in order to promote Correct Use. The goals of monitoring and evaluation overlap, which are to present data that assist decision-making, improve outcomes, and reach objectives. WHO and UNICEF (2012) defines monitoring as, "an ongoing process by which stakeholders receive regular feedback on progress made towards achieving objectives" (p. 10). And evaluation is defined as, "an objective appraisal of either completed or ongoing activities to determine the extent to which they are achieving the stated objectives" (p. 10). Until recently, there was a need for integrated tools and indicators to support monitoring and evaluation of HWTS interventions. Two key documents, *A Toolkit for Monitoring and Evaluating Household Water Treatment and Safe Storage Programmes* (WHO & UNICEF, 2012) and *Access and Behavioral Outcome Indicators for Water, Sanitation, and Hygiene* (USAID, 2010), have addressed this need. But before further discussion on monitoring and evaluation efforts, it is first necessary to understand what constitutes improved and unimproved drinking water sources.

3.1. Improved and Unimproved Drinking Water Sources

The overall success of a drinking water supply program can be measured by the proportion of a population with sustainable access to safe drinking water as mandated by Millenium Development Goal (MDG) 7, Target 7c. There are a variety of definitions of access or coverage, many with different requirements in regards to safety or adequacy. WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation is delegated to measure sustainable access to safe drinking water in order to evaluate progress towards this specified MDG target. The JMP monitors the use of improved and unimproved drinking water sources by households through countrywide demographic and health surveys, among other methods. An improved source is defined as, "one that, by nature of its construction or through active intervention, is protected from outside contamination, in particular from contamination from fecal matter" (WHO & UNICEF, 2010). Improved sources are assumed to most likely provide safer drinking water than unimproved sources. Improved and unimproved water supplies are summarized as follows according to the JMP.

Improved drinking water sources*:*
- piped water into dwelling, yard, or plot
- public tap or standpipe
- tubewell or borehole
- protected dug well
- protected spring
- rainwater collection

Unimproved drinking water sources:
- unprotected dug well
- unprotected spring
- cart with small tank or drum provided by water vendor
- tanker truck provision of water
- surface water (river, dam, lake, pond, stream, canal, irrigation channel)
- bottled water

The assumptions and definitions of improved and unimproved drinking water sources have been scrutinized. Schafer, Werchota, and Dalle (2007) disagree that access to a protected water source as defined by JMP indicates access to safe water. The forms of protection often observed in protected boreholes, wells, and springs are only safeguards against sources becoming contaminated by animals or to prevent children from falling in, but often no steps are taken that significantly impact water quality. Schaefer et. al (2007) do consider a concrete platform, drainage channel, and a hand pump or mechanical pump connected to tubewells/boreholes as adequate protection. However, this can also be an erroneous assumption. Pollution can still occur in a well with a lid via latrines located nearby (within 30 meters) or other contamination sources, which was the case in Mato's (2002) study. Mato (2002) found that approximately 60% of randomly selected boreholes in Dar Es Salaam, Tanzania tested positive for fecal coliform presence.

3.2. Survey Design

3.2.1. HWTS Correct Use Indicators

Measuring indicators is an important step in the program management cycle, which includes baseline data collection, midterm, and final evaluations (WHO & UNICEF, 2012). Monitoring indicator performance and degree of target realization during program implementation is highly recommended (USAID, 2010). The data collected can in turn help inform and improve decisions related to program strategies, work plans, and funding (WHO & UNICEF, 2012).

The documents by WHO and UNICEF (2012) and USAID (2010) address the selection of appropriate indicators to help answer HWTS monitoring and evaluation questions. Due to the nature of the author's research, indicators that relate to and address Correct Use of HWTS will be analyzed. The comparison between the two references provides some interesting results, as well as leads to useful recommendations.

The United States Agency International Development's (USAID) *Access and Behavioral Outcome Indicators for Water, Sanitation, and Hygiene* presents a comprehensive list of indicators that address general objectives and measurement of outputs and outcomes, which are typically sought by international donors and development projects. Indicators are presented in two distinct categories, which are "Essential Indicators" which are suggested for all WASH programs and "Essential and Expanded Indicators." The latter category is a more comprehensive list and is included for managers, who desire to address a larger gamut of issues. Each indicator is meticulously described and explained through the components of rationale/critical assumptions for indicator, data source, data analysis, issues/limitations, example target settings, survey questions, and indicator calculator. Apart from the water quality indicators, the data sources recommended take the form of a household survey. A combination or the entirety of all components can serve the interests of different users and readers. The indicators introduced in the manual favor the use of observation and objective tests to collect behavioral data. Two water quality indicators are presented in the document (USAID, 2010) because for the case of HWTS, "experts and practitioners often argue that the most reliable measure of whether or not a water treatment practice is being performed is a water quality test" (p. 3).

A Toolkit for Monitoring and Evaluating Household Water Treatment and Safe Storage Programmes by WHO and UNICEF (2012) introduces indicators that focus on:

- Reported and observed use;
- Correct, Consistent Use and storage;
- Knowledge and behavior;
- Other environmental health interventions;
- And water quality.

The development of these indicators took into account the initial work accomplished in USAID's document, in addition to recent findings. Monitoring the indicators presented in this publication, program managers can project realistic health benefits of the HWTS intervention since the indicators are directly associated with health outcomes. The indicators are designed to inform estimates of risk reduction and health impacts, as well as provide the ability to compare data across various programs in different countries (WHO & UNICEF, 2012).

An example of applying Correct, Consistent Use and storage indicators, as described in WHO and UNICEF's (2012) document, was demonstrated in Kenya. A survey was administered to assess the knowledge of Correct Use of chlorine tablets and flocculent/disinfectant sachets during an emergency response program (Lantagne & Clasen, 2011). The survey results indicated that understanding after one training session was high if the HWTS technology was easy to use, i.e. having a two-step procedure, but low if the procedure was more complex, consisting of more than two steps. Therefore, it was concluded that more focus needed to be given to follow up training for multi-step procedures to increase understanding and promote Correct Use. The use of indicators led to a solution that addresses the problem encountered.

Both documents share a great deal in common in their interpretation of HWTS indicators. This can be attributed to USAID's work serving as a basis for WHO-UNICEF's report. However, there is contrast in how the indicators are presented. The USAID reference rigorously explains the context and origin of each indicator, in addition to the various ways the indicator can be applied and measured. The attention to each indicator provides a more practical, comprehensive approach to its implementation within a monitoring and evaluation framework. The *Toolkit* describes the HWTS indicators more conceptually, and supplies one option in its measurement. Furthermore, the *Toolkit* presents many real world situations that exhibit the use of specific indicators but does not explicitly detail implementation. Rather it documents failures and shortcomings of HWTS intervention programs. Each reference possesses its advantages and drawbacks. When both are utilized together, the researcher is able to comprehend a more complete picture of how HWTS indicators can impact monitoring and evaluation endeavors.

Abt Associates (2012) conducted an evaluation of HWTS pilot products in several countries. A report was compiled presenting results from these programs. A pertinent component of the report, related to the author's research, includes data collection instruments, namely a Correct Use checklist. Their Correct Use checklist was comprised of indicators addressing verification of current use, assembly, storage, and maintenance. Indicators were solely based on observations that exhibit Correct or incorrect Use of the HWTS method (Abt Associates, 2012). This survey design is ideal for quick survey administration in order to cover a large number of households. Incorporating observational Correct Use indicators along with the indicators previously mentioned in the USAID and WHO-UNICEF reports can mitigate potential self-reporting pitfalls and substantiate respondents' verbal answers.

3.2.2. Sample Size and Random Sampling Recommendations

The 4th edition of WHO's *Guidelines for Drinking-water Quality* provides recommendations regarding sample size as well as survey procedures. The *Guidelines* were followed in the author's work plan. Sampling frequencies should balance benefits and costs associated with gathering data. These frequencies are typically determined by population size or volume of water supplied to determine the extent of population risk. Microbial aspects require more sampling and analysis than chemical constituents because even short periods of microbial contamination cause long-term disease, while episodes of chemical contamination, categorized as an acute health concern, are less likely to occur. The type and likelihood of contamination can depend on seasonality, especially with rainfall and droughts. Sampling is recommended to be carried out in a random fashion, however should be increased during times of epidemics, flooding, or emergency operations.

Guidelines for Drinking Water Quality also addresses the use of surveys. In most circumstances, it is not feasible to perform a comprehensive surveillance of all community or household supplies. Therefore, surveys should be focused and administered to target the level of interest, i.e. regional or municipal level. Surveys should address issues of source water quality, treatment efficacy, and the quality of distributed or household-treated and household-stored water. The main purpose is to determine whether contamination occurs at the source or in the household. "Systematic determination of continued, correct, and effective use and management is recommended so that deficiencies in use and management can be identified and corrected by those responsible" (WHO, 2011b, p. 83).

WHO and UNICEF (2012) also suggest approaches to determine sample size and plans for a monitoring and evaluation program. It recommends the examination of a minimum number or proportion of households per unit, i.e. 10% or 50% of beneficiary households in a community, which depends on a host of variables. These variables may include the availability of resources for collecting and evaluating data, household population, and traveling constraints. It is essential to sample a random, non-biased selection. Examples of sampling methods are community mapping, spin the bottle, satellite imagery, and randomizing a line-list. Rigorously adhering to the chosen method and explaining the reasons why the selection method was implemented is paramount. Furthermore, recording replacements when households could not be reached is important.

3.3. Monitoring and Evaluation Field Studies

Stauber, Kominek, Liang, Osman, and Sobsey (2012) conducted a controlled trial that monitored and evaluated the plastic BioSand filter (BSF) in Northern Ghanaian rural communities. The main goal of this study was to examine the declines of diarrheal disease incidence and improvements of household drinking water quality due to the HWTS intervention. The longitudinal study compared households that did and did not receive the BSF from June to December 2008. Stauber et. al (2012) reported that the plastic BSF was reducing the prevalence of diarrhea by 60%, *E. coli* by 97%, and turbidity by 67%, which is comparable to results of similar HWTS trials.

Peletz (2006) surveyed 50 Northern Ghanaian households, consisting of mostly middle-class homes that have and have not purchased the AfriClay filter, and collected applicable drinking water samples. Her study concluded that 93% of customers continued to use the HWTS technology within 6 months of purchase. Peletz (2006) also emphasized that there is a great need for safe water in the region, where rural traditional communities were more likely to suffer from diarrhea and lack of improved drinking water. The work of Peletz (2006) was the basis for the research conducted by Johnson (2007), which consisted of household surveys and water quality monitoring pertaining to AfriClay filter use within middle-class and rural communities. Johnson (2007) found that individuals residing in rural, traditional households with filters had a 69% lower risk of diarrhea than individuals in similar households without a filter. These studies highlight the fact that using the ceramic pot filter gives dramatic diarrheal disease reduction even though the achieved bacteria reduction ranged from 1 – 2 log reduction value (LRV). Rural, traditional communities experience high diarrheal rates and even adopting small steps through HWTS methods can yield significant health benefits. Collin (2009) substantiated the applicability of ceramic pot filters in the Northern Region of Ghana rather than disseminating BioSand filters (BSF). As BSF technology has inherent pitfalls, such as its lack of built-in safe storage and rigorous maintenance. Furthermore, BSF technology is more appropriate for low turbid drinking water than high turbid water, which is prevalent in the Northern region. The learning from these studies is to proceed with ceramic filters in the context of Northern Ghana, which is what PHW did.

Besides Peletz (2006), Johnson (2007), and Collin (2009), four other MIT Master of Engineering theses by Lu (2012), Clopeck (2009), Ziff (2009), and Stevenson (2008) give important insights into monitoring and evaluation of HWTS technology interventions.

To address the monitoring and evaluation of this distribution, Lu (2012) presents the components of a three-part evaluation framework, baseline results, and recommendations for measuring the use of the ceramic pot filter as part of a contract with the Rotary Club to sell ceramic pot filters and install Tippy-Tap hand washing stations in 1,250 Northern Ghanaian households. The framework is comprised of a baseline survey, one-month follow-up survey, and a six month follow-up survey. The baseline surveys administered in January 2012, addressed household characteristics, water source, household water management, hand-washing practices, as well as diarrheal and respiratory disease prevalence. A total of 429 households were sampled across 20 villages.

Clopeck (2009) surveyed 309 households that purchased a ceramic pot filter from Pure Home Water between 2005 and 2008. The purpose of her survey was to determine, what was defined at the time as, "sustained" use, which is synonymous with what is now referred in this thesis to as Continuous Use of the ceramic pot filter. She conducted water quality analyses through the use of Colilert and the 3M Petrifilm tests, also known as the "EC Kit", to evaluate the field performance of the HWTS. Findings from the survey suggested that household income, reported water source, and price paid for filter were linked to the Continuous Use or disuse of the filter. The average total coliform and *E. coli* counts for the ceramic pot filter using the lower test detection limits of the water quality tests corresponded to a "low" risk level, while the upper test detection limits yielded an "intermediate" risk level. The ceramic pot filter exhibited a 1.42 log reduction of total coliform and 0.99 log reduction of *E. coli* on average for the lower detection limits, and 0.95 and 0.75 log reductions for upper test detection, respectively.

Ziff (2009) conducted a field study in 24 households in Northern Ghana, evaluating the viability of the siphon filter. Her study was comprised of household visits, an effective use survey (which is referred in this thesis as a Correct Use survey), and water quality analysis. The households that were sampled had low and high turbid water sources, and an economic status ranging from low to middle class. Recontamination of treated water was observed and determined to be due to filter taps resting on contaminated water containers or contact with contaminated hands. On average, the siphon filter removed 90.7 % of total coliform and 94.1 % of *E. coli.* These results may be affected by the recontamination issue mentioned above. Ziff recommended a post-filtration safe storage container design to maintain the microbial quality of the treated water.

In relation to Ziff's (2009) study, WHO's *Guidelines for Drinking-water Quality* refers to the importance of the user's responsibility in making sure their actions do not introduce a negative effect on water quality. "Consumer actions may help to ensure the safety of the water they consume and may also contribute to improvement or contamination of the water consumed by others" (p. 15). Moreover, " for water stored in the home, protection from contamination can be achieved by use of enclosed or otherwise safely designed storage containers that prevent the introduction of hands, dippers or other extraneous sources of contamination"(p. 59).

Stevenson (2008) focused on a framework for monitoring effective use of various HWTS technologies. Eight technologies were considered, namely dilute bleach solution, Aquatabs®, solar disinfection, cloth filters, ceramic pot filters, BioSand filters, PUR, and their related safe storage units. Stevenson investigated the HWTS implementations in Ethiopia and Ghana. Interviews and water quality tests were conducted. The monitoring observations, tailored for each HWTS technology, were categorized by treatment, safe storage, maintenance, replacement period, physical inspection, and water quality parameters.

As seen from the many literature sources reviewed above, numerous factors must be considered in implementing monitoring and evaluation efforts for a specific HWTS technology.

The purpose of gathering monitoring and evaluation data is to achieve the major gain of HWTS, which is improved health. The gains of monitoring and evaluation efforts will only be attained if the data is used to influence future programs, policies, and investments. This will prove to be a valuable resource in leading further implementation and scaling up efforts.

3.4. H_2S Bacteria Test

The author reports on results from 9 measurements of H_2S Most Probable Number (MPN) in **Section 5.4.1**. There was little literature on H_2S MPN, therefore the literature reviewed in this topic addresses the H_2S Presence/Absence (P/A) test, not the H_2S MPN test. Although this is the case, it is worthwhile to examine for the purposes of diligence and gaining progress within this field. The H_2S P/A test, as its name suggests, yields a qualitative result of either a "negative" or "positive" for the potential of fecal contamination, while the H_2S MPN test provides a quantitative result in units of MPN/100 mL, a statistical yet enumerative result.

One of O'Keefe's (2011) study objectives was to verify the accuracy of the 20 mL H_2S test as a single P/A indicator for fecal coliform. She sampled and tested 111 unique water source samples Tamale, Ghana during January 2011. O'Keefe (2011) found that the 20 mL H_2S P/A test was highly accurate for testing various water sources with 10% for false negatives and 90% true value, using the Fisher's Exact test, in detecting the presence of *E. coli*. when compared to the standard IDEXX Quanti-Tray®/2000 MPN method. The study's results showed that there were associated errors of 22% for improved water sources (n = 26) and 6% for unimproved water sources (n = 85). The study concluded that due to these favorable statistical results, the P/A test is viable to test microbial quality.

Chuang et. al (2011) sought to compare and confirm four low-cost microbiological tests, including the H_2S P/A test, against the standard IDEXX Quanti-Tray®/200 MPN method. The study documents sampling and testing over 500 water samples from Capiz Province, Philippines and Cambridge, Massachusetts. The authors concluded that using either of the two test combinations, 100 mL H_2S test + Petrifilm™ or 20 mL H_2S test + Easygel, yielded better results than a single test for indicating the presence of *E. coli*.

Yang et. al addressed the influence of bacterial density and sample volume (20 mL or 100 mL) on the accuracy of the H_2S test compared to standard tests for either thermotolerant coliforms or *E. coli*. Yang et. al gathered and reviewed pertinent data from 19 different studies in order to systematically review and draw conclusions. Accuracy was measured by sensitivity, "proportion of water samples above a threshold indicator bacteria density that are correctly identified by the

H_2S method," and specificity," proportion of uncontaminated water samples below a given indicator bacteria threshold density that are correctly identified by the H_2S method." The authors concluded that sensitivity increased and specificity decreased when contamination increased from 1 CFU/100 mL to 100 CFU/100mL. Furthermore, sensitivity increased and specificity decreased when the sample volume changed from 20 mL to 100 mL.

4. Methodology

4.1. Survey Design

The Correct Use survey was administered to a representative number of households, in the village of Yipelgu, that have received the AfriClay filter through the UNICEF-Ghana distribution. The survey, which can be found in **Appendix A**, addresses pertinent factors related to Correct Use, such as filter assembly, treatment practices, storage, and maintenance. A Correct Use checklist has been generated in order to calculate % Correct Use. The survey also includes general questions about household information and dry/wet season water sources.

Numerous prior surveys and references were studied in order to identify pertinent factors related to correct filter use. USAID's *Access and Behavioral Outcome Indicators for Water, Sanitation, and Hygiene* and WHO-UNICEF's *A Toolkit for Monitoring and Evaluating Household Water Treatment and Safe Storage Programmes* influenced the design of the Correct Use survey. The author selected the most appropriate indicators to include in her survey that aligned with the study's objectives. Additionally, the AfriClay filter's Training Manual was rigorously scrutinized, as well as previous Master of Engineering students' theses related to monitoring and evaluating HWTS, to further inform the survey design.

The survey was reviewed and approved by MIT's Committee on the Use of Humans as Experimental Subjects (COUHES) prior to the research period.

4.2. Survey Sample Size

The ideal case from a statistics standpoint is to survey every household within each group considered. However, due to the constraints of time, funds, and limited number of surveyors (the survey team was comprised of the author and one PHW staff person), this was not feasible. An appropriate proxy is to determine a sample size and then randomize with 100% participation. As a rule of thumb, if one is testing for something that is more likely in a population, a smaller sampler size is needed. If one is testing for a variable that is less likely, a greater size must be sampled. A sample size of less than 20 is considered statistically small; and a size over 20 is considered statistically justifiable, where an even larger sample further validates the data set. An appropriate sample size allows for statistical rigor.

The target sample size for beneficiary households in Yipelgu was calculated using the Raosoft Sample Size Calculator, an online tool. The computed sample size was 85, which takes into account 700 households, 10% margin of error, 95% confidence level, and 50% response distribution. Furthermore, for every one of the 85 households surveyed, the appropriate water quality test samples were collected as specified in **Section 4.5**. Analysis of the data suggests, but cannot prove direct relationships due to the use of a limited sample size.

4.3. Random Sampling Plan

Once the sample size has been determined, the process of random sampling has to be established, as per the statement, "If conducting household surveys, it is important to sample a random, non-biased selection and clearly document the methodology for selection" (WHO & UNICEF, 2012, p. 34).

4.3.1. Initial Random Sampling Plan: Numbered Compounds

The random sampling method initially planned was as follows[1]. Through the use of ArcGIS, mapping and spatial analysis software, satellite imagery of the village of Yipelgu was obtained, as depicted in **Figure 4-1**.

Figure 4-1: ArcGIS satellite imagery of Yipelgu, Northern Ghana.

The layout of the village, as well as the number of compounds and households can be distinguished from this aerial view. For the purposes of this project, a household was defined as the unit of one wife, her children, and any immediate family living with her in a discrete dwelling. Since the UNICEF-Ghana distribution excluded dissemination to the men, rectangular-shaped dwellings were not included in the random sampling process.

In order to initiate the process of random sampling, each compound was designated with a number starting from 1 to "X". Households were then numbered from 1 to the total number of households within each compound, keeping in mind the exclusion of rectangular dwellings and numbering the female (round shaped) houses observable on **Figure 4-1**. Therefore, each household can be identified by two numbers, the first being the compound it belongs to and the second denoting its location within the compound. The households were assigned a unique,

[1] Establishment of sample sizes and the random sampling procedure was discussed with Mr. Ezra Haber Glenn, Senior Lecturer at MIT's Department of Urban Studies and Planning, who also provided expert guidance in the data analysis.

random number through Microsoft Excel's built-in 'Random' function. Next, the random numbers were ordered in an arbitrary manner, i.e. increasing or decreasing order. From this ordered list, the first 85 households were selected to be surveyed. Randomization is achieved since the assigned random number governed the order of the finalized list.

The random sampling technique does not specify which households have filters and which do not, since this information was not available. In order to combat this issue and meet the specified target sample size goal, the randomly selected households were planned to be visited; regardless of this knowledge. If a household that has yet to receive a filter is encountered, it will be passed over and the next beneficiary household would be surveyed.

With this random selection of households, the author planned to reference the satellite map and plan the most efficient route in visiting these households. This would save time and prevent traveling back and forth from one side of the village to the other on a given day.

Although this randomization sampling plan was constructed to be statistically rigorous, it was not feasible to implement in the field. Finding the selected household was difficult and extremely time consuming. The researcher also had to consider meal times, market days, and prayer schedules when most Yipelgu inhabitants were not available for taking the survey.

4.3.2. Final Random Sampling Plan: Map Quadrants

In order to achieve the target sample size, a revised randomization plan was executed. The details of this revised plan are outlined below:

- The map of the village, shown in **Figure 4-2**, was divided into quadrants (Northeast, Northwest, Southeast, and Southwest). The divisions were aligned with the main dirt roads.
- A certain number of days were assigned to each quadrant, where more days were designated in accordance to household density.
    - Northeast – 3 days
    - Northwest – 4 days
    - Southeast – 2 days
    - Southwest – 2 days
- Within the assigned days specified for a particular quadrant, as many surveys were conducted from the researcher's arrival at 9:00 AM to 1:00 PM.
- If a compound consisted of more than one beneficiary household, all of them would be surveyed to prevent bias.

The revised random sampling plan achieves geographic spread, and provides representative surveys for each quadrant. A balance between statistical rigor and logistic feasibility must be reached in planning and implementing a randomization process.

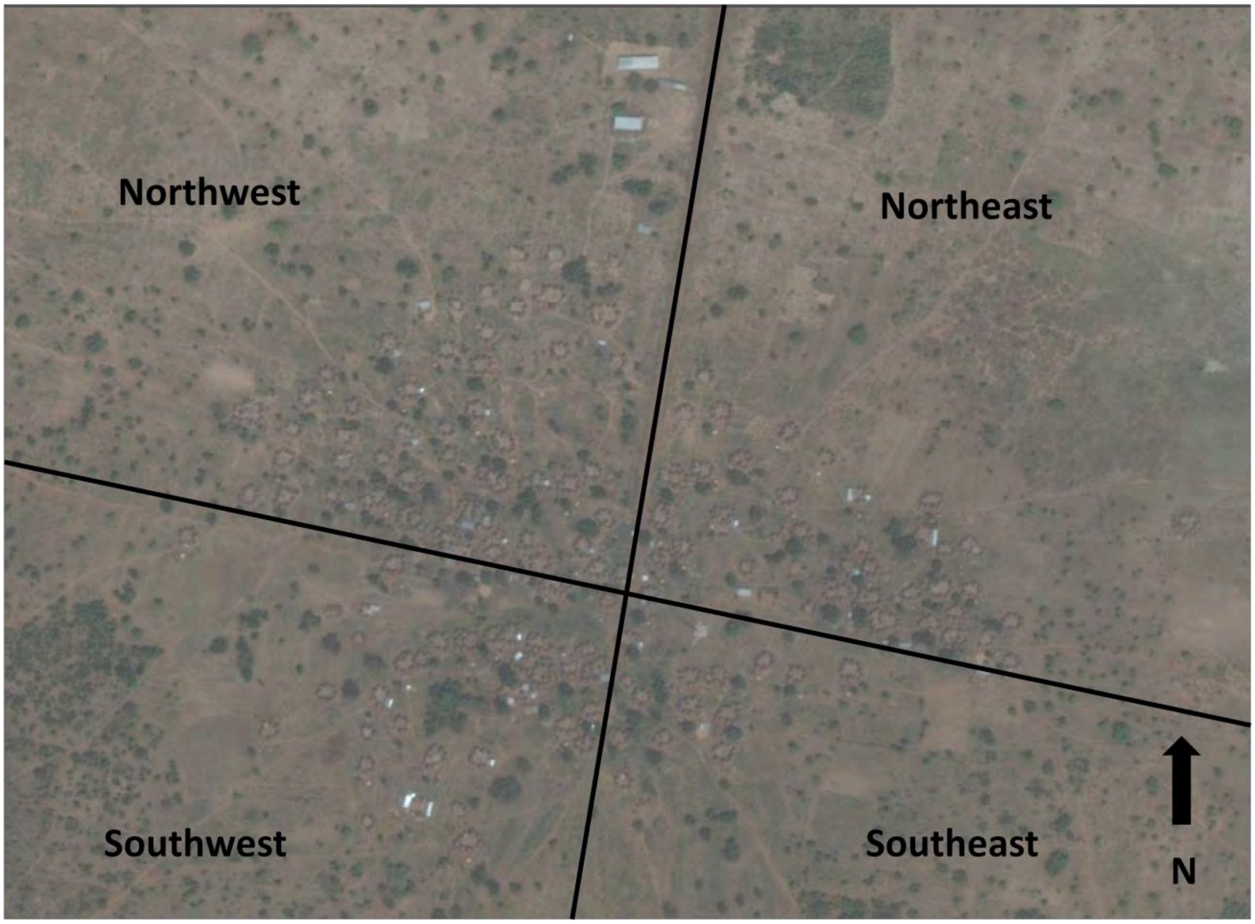


Figure 4-2: Final random sampling plan: map quadrants.

4.4. Indicator Organisms

Monitoring and evaluating household water treatment and safe storage (HWTS) technologies entail not only analysis of behavioral indicators measured in surveys and direct observation, but also water quality testing. In order to determine whether the performance of drinking water supply complies with health based targets, indicator organisms are tested. Total coliform (TC) and *Escherichia coli* (*E. coli*) are widely used as indicator organisms. Hydrogen sulfide (H_2S) production can also be used as an alternative indicator (WHO & UNICEF, 2012).

Microbial contaminated water sources can be identified in two ways. One method entails directly testing for pathogens. This is considered a more risky and expensive process. Therefore, water quality targets are not usually set for pathogens. This leads into the second method of identifying contaminated water sources, which is to measure indicator organisms to approximate presence of pathogens and fecal contamination (WHO, 2011b).

According to WHO (2011b), an ideal indicator organism should meet the following requirements:

1) Be universally present in feces of humans and animals in large numbers;
2) Will not multiply in natural waters;
3) Persist in water in a similar manner to fecal pathogens;
4) Be present in higher numbers than fecal pathogens;
5) Respond to treatment processes in a similar fashion to fecal pathogens;
6) Be readily detected by simple, inexpensive culture methods.

The total coliform group, comprised of gram negative, non-spore forming, rod shaped bacteria, is regarded as the most reliable indicator for drinking water quality. Coliforms make up the broadest category of indicator organisms. The presence of *E. coli*, which is a single species subcategory of total coliform, provides evidence of recent fecal pollution. *E. coli* should not be present in drinking water. For many developing countries, many households and small-scale drinking water systems do not meet water safety requirements, including the absence of fecal microorganism indicators. Therefore, practical and feasible goals should be set (WHO, 2011b).

4.5. Water Quality Test Procedures

Water quality testing is an important measure of filter performance and use. "In the specific case of household water treatment and storage, experts and practitioners often argue that the most reliable measure of whether or not a water treatment practice is being performed is a water quality test" (USAID, 2010, p. 3). In the case of the Yipelgu UNICEF-Ghana distribution, the water quality monitoring consisted of three different tests, two of which were performed by the author.

The water quality parameters that were tested and analyzed included turbidity, total coliform/*E. coli* and H_2S bacteria. Two samples, stored and filtered water, were collected from each beneficiary household. Stored water undergoes pre-treatment, sedimentation and bacteria die-off, prior to filtration. Stored water is defined in this thesis as water that originates from a raw water source and is stored separately from the AfriClay filter system. This water is usually kept in a ceramic, clay storage vessel either inside the household or outside in the compound's courtyard (**Figure 4-3**).

Figure 4-3: Stored water samples.

Filtered water was sampled directly from the AfriClay filter tap (**Figure 4-4**). The source waters of the village were also sampled. The testing of blanks and duplicates (2% of the total number of each test) was also conducted to prevent contamination and guarantee precision. All water quality tests were carried out as per the 22nd edition of *Standard Methods: for the Examination of Water and Wastewater*.

Figure 4-4: AfriClay filter in Yiplegu household being sampled by the author.

4.5.1. Turbidity Testing

Turbidity is an important water quality parameter for evaluating a HWTS method, for the following reasons: (1) the performance of disinfection-only treatment methods decreases with high turbidity; (2) the user's acceptability of the water decreases with increasing turbidity levels; and (3) turbidity reduction can quantify treatment performance (WHO & UNICEF, 2012).

Suspended and colloidal matter, i.e. clay, silt, finely divided organic and inorganic matter, cause turbid water. Turbidity is determined by the optical property that results in light scatter and absorption, instead of light transmission without direction change or flux level, through a water sample. The preferred instrument to measure turbidity is an electronic nephelometer, which report in nephelometric turbidity units (NTUs). The reading for turbidity increases as the intensity of light scatter increases. The author used a HACH's 2100P Turbidimeter to measure the turbidity of all collected samples (stored, filtered, and raw source). The turbidimeter was calibrated prior to any field collection using stabilized formazin turbidity standards (at 0, 20, 100, 800 NTU) as per the manufacturer's instruction manual.

Clear, glass sample cells were placed into the turbidimeter. The cells were cleaned thoroughly both inside and outside between each sample tested. The sample cell was always handled by its plastic cap, to avoid any smudges to the glass that could interfere with the turbidity reading. The cells were filled with thoroughly agitated samples and devoid of any air bubbles. The procedure has been adapted from the HACH 2100P Turbidimeter instruction manual, and is described below (HACH, 2008).

1. Thoroughly clean the sample cell.
2. Collect a representative sample in a clean container. Fill a sample cell to the line (about 15 mL), taking care to handle the sample cell by the top.
3. Wipe the cell with a soft, lint-free cloth to remove water spots and fingerprints.
4. Apply a thin film of silicon oil. Wipe with a soft, lint-free cloth to obtain an even film over the entire surface. This step will mask minor imperfections and scratches on the cell which may lead to inaccurate readings. This step will likely be skipped in the field and extra care taken to keep sample cells from being damaged.
5. Wipe off excess oil (if applied).
6. Press I/O on the turbidimeter.
7. Insert the sample cell into the instrument cell so the diamond or orientation mark aligns with the raised orientation mark in front of the cell compartment. Close the lid.
8. Press RANGE on the turbidimeter. Select manual or automatic range mode.
9. Press SIGNAL AVERAGE on the turbidimeter.
10. Press READ on the turbidimeter. The display will show "----", then the turbidity in FNU (Formazin Nephelometric Units). Record the turbidity after the lamp symbol turns off. Note: Hach literature appears to use FNU and NTU (Nephelometric Turbidity Units) interchangeable, and they appear in literature references to be practically identical at low ranges.

4.5.2. Total Coliform and *E. coli* Most Probable Number (MPN) Tests

Bacteria that are related to disease-causing organisms, but do not cause disease themselves, are called microbial indicators. Total coliform and *E. coli* can be measured for these purposes (WHO & UNICEF, 2012). According to WHO's *Guidelines for Drinking-water Quality*, safe water should have 0 *E. coli* CFU/100 mL. The IDEXX Quanti-Tray/2000® trays and Colilert® 24-hour reagent were used to determine counts of total coliform and *E. coli.* It is based on a procedure described in *Standard Methods: for the Examination of Water and Wastewater* (SM # 9223), which is referred to as the enzyme substrate coliform test. This testing method is regarded as the "standard" for Pure Home Water quality control operations. The procedure, which has been adapted from the overview instructions available on IDEXX's website, is outlined below (IDEXX, 2013).

Before commencing tests, the author cleaned and changed from field to lab attire.

1. Wash hands thoroughly.
2. Sanitize work area by wiping down counters with rubbing alcohol.
3. Turn on IDEXX Quanti-Tray® Sealer 2X.
4. Transfer sample to sterile bottle with seal.
5. Add Colilert® 24-hour growth media to sterile bottle.
6. Seal bottle and shake to mix reagents.
7. Label the underside of the IDEXX Quanti-Tray® with name, sample, and date.
8. Grasp IDEXX Quanti-Tray® vertically with dominant hand. With non-dominant hand, pull tab of IDEXX Quanti-Tray®.
9. With non-dominant hand, pour entire contents of sterile bottle into the IDEXX Quanti-Tray®.
10. Feed tray into IDEXX Quanti-Tray® Sealer 2X, wedge side first.
11. Incubate at 35 ± 0.5°C for 18 or 24 hours, depending on time indicated for Colilert® reagent.
12. Read results
    a. Colorless = negative
    b. Yellow = positive for total coliforms
    c. Yellow/fluorescent = positive for *E. coli*

The appropriate dilutions were conducted as to diminish too numerous to count (TNTC) and below detection limit (BDL) results. In this particular study, it was determined to use a 1:100 dilution for stored and 1:10 dilution for filtered samples. Either a 1:100 or 1:1000 dilution was used to test the raw water samples. These dilutions primarily concentrated on capturing total coliform results as *E. coli* is not necessarily present in all the samples. Discussion on dilutions and data management can be found in **Section 5.1**.

4.5.3. Hydrogen Sulfide (H_2S) Bacteria Most Probable Number (MPN) Testing

The hydrogen sulfide (H_2S) bacteria test can serve as an alternative fecal indicator test (WHO, 2011b). The purpose of conducting low-cost H_2S bacteria tests was to possibly correlate its Most Probable Number (MPN) results to that of the expensive standard method of IDEXX Quanti-Tray®/2000. H_2S bacteria tests are more appropriate for water quality testing in Ghana and other developing countries since it is fully quantitative and inexpensive.

Quality Control Report, an internal PHW document by Joshua Hester (M.Eng '11), describes the experimental methods and procedures for H_2S MPN testing. The procedure entails preparation of a triple batch of H_2S medium to accommodate a series of fifteen bottles for each filter tested. Five bottles are prepared at a controlled amount of either 0.02, 0.2, or 2 mL of the sample and then respectively diluted to 20 mL. These tests were performed on split samples by a Pure Home Water technician. The filters (each associated with paired stored and filtered samples) were tested for H_2S bacteria. The tests were then interpreted and recorded by the author after a 24 hour period. The presence of any black or gray hue in the bottle or on the paper was interpreted as a positive reading. The number of positive results were either plugged into the Thomas equation (**Equation 4-1**) or entered into the MPN Calculator Excel spreadsheet in order to determine MPN results.

Equation 4-1: Thomas equation (Tchobanoglous, 1985).

$$\text{MPN/100 mL} = \frac{\text{number of positive tubes x 100}}{(\text{mL of sample in negative tubes x mL of sample in all tubes})^{1/2}}$$

4.6. Field Data Collection

Eighty-five beneficiary households were surveyed, two water quality samples (stored and filtered) were collected from each household, and 13 community water sources were sampled during the research period of January 4 – 19, 2013. A Pure Home Water staff member, either Abdul-Karim Alale, Daniel Appiah, or Peter Atuba, accompanied the researcher and acted as translator/guide for a given day. The author would state the survey consent script and proceed to the survey questions if consent was given. Each survey question was read by the researcher, then translated by the PHW employee, and finally carefully recorded onto paper copies of the survey. All surveys were given a number based on the order of visitation. Pastor Alhasan Nendoo also accompanied the author and translator. The pastor served as a local guide and assisted in locating the community water sources.

Each sample (stored, filtered, and source) was collected in two 150 mL sterile VWR sterile sampling bags as depicted in **Figure 4-5**. A total of 300 mL of each sample was collected, which accommodated all three water quality tests, i.e. 100 mL for IDEXX Quanti-Tray®/2000, 120 mL for H_2S bacteria, and 15 mL turbidity tests. The stored water was collected from the vessel the respondent designated as the container from which she fills the filter. Filtered water was collected directly from the tap into the sampling bag. Raw water samples were collected by adhering to the proper protocol for manual sampling described in *Standard Methods: for the Examination of Water and Wastewater* which states, “Take samples from a river, stream, lake, or pool by holding the bottle near its base in hand (use gloves) and plunging it, neck downward, below the surface. Turn bottle until neck points slightly upward and mouth is directed toward the current. If there is no current, as in the case of a reservoir, create a current artificially by pushing bottle forward horizontally in the direction away from the hand” (APHA et. al, 2012, p.9-34). VWR sterile sampling bags were used instead of bottles in this study. Samples were kept in sealed coolers until arrival at the PHW laboratory, where they were refrigerated until tested. Water quality tests were conducted within 24 hours of sample collection. All samples were thoroughly agitated before testing to ensure the representative distribution of particles and bacteria. Equipment and work area were meticulously cleaned and sterilized before and after handling each sample.

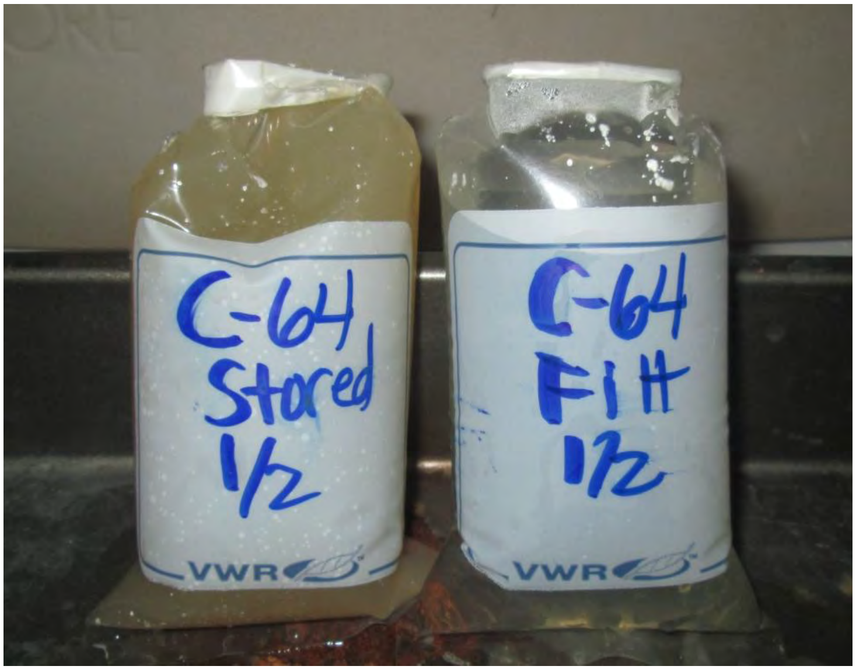


Figure 4-5: VWR sterile sampling 150 mL bags.

4.7. Drinking Water Standards

The 4th edition of WHO's *Guidelines for Drinking-water Quality* states that total coliform and *E. coli* should be non-detectable in any 100 mL sample of drinking water. If *E. coli* is detected, immediate action should be taken. However, the *Guidelines* also mention that since the majority of rural water sources in developing countries are likely to be contaminated, setting up medium-term targets is more appropriate, which is what has been done in this study.

The following tables are a summary of the drinking water guidelines that the researcher used to evaluate the field data collected. Specific adjustments to these guidelines for the purpose of the study can be found in **Section 5.4**.

Table 4-1: WHO risk level categories (WHO & UNICEF, 2012).

Level of *E. coli* Contamination	WHO Risk Level
< 1 CFU/100 mL[a]	No action required
1 – 10 CFU/100 mL	Low risk
11 – 100 CFU/100 mL	Intermediate risk
101 – 1000 CFU/100 mL	Very High
> 1000 CFU/100 mL	Very High [*sic*]

[a] Colony forming unit (CFU) is the unit of measurement for the earlier standard method, which was membrane filtration.

Table 4-2: Derivation of targets (WHO, 2011a).

WHO Target	Log_{10} reduction required: **Bacteria**	Log_{10} reduction required: **Viruses**	Log_{10} reduction required: **Protozoa**
Highly protective	≥ 4	≥ 5	≥ 4
Protective	≥ 2	≥ 3	≥ 2
Interim*	Achieves "protective" target for two classes of pathogens and results in health gains		

Furthermore, WHO and UNICEF (2012) suggests that drinking water should exhibit a turbidity of <5 NTU, and if feasible, a turbidity of <1 NTU in resource-limited conditions.

To measure overall filter performance, total coliform and *E. coli* log reduction values (LRVs) for each of the 85 filters were calculated. Log reduction values are calculated using **Equation 4-2**.

Equation 4-2: Calculating LRVs.

$$\text{Log reduction value (LRV)} = \log_{10}\left(\frac{\text{stored water sample}}{\text{filtered water sample}}\right)$$

where,
stored and filtered water samples are in units of MPN/100 mL.

Converting MPN results into LRVs facilitates comparison between AfriClay filter performance and international guidelines as discussed above in **Tables 4-1** and **4-2**. Once all LRVs are calculated, each filter is associated with a total coliform LRV and an *E. coli* LRV, which are not necessarily the same value due to the different indicator organisms and test detection.

4.8. Statistical Analysis

This section describes the statistical methods used in this study. The sequence of using applicable statistic methods, specifically (1) histograms, (2) significance tests, and (3) simple linear regression, ultimately helped the author to identify important survey variables that might affect filter performance in the household setting.

(1) A histogram divides a range of values of the variable into classes. It displays either the count or percent of observations that are categorized into each class (Moore, McCabe, & Craig, 2012). Histograms of total coliform and *E. coli* LRV are generated to visualize the range and frequency of filter performance, as well as to pinpoint filters that performed at the high and low ends.

(2) A significance test is a method to compare observed data with a hypothesis (Moore et. al, 2012). Significance tests were used to determine the Correct Use variables that might affect filter performance.
   a. Chi-square test – to compare Correct Use checklist categorical variables
   b. Two-sample t test – to compare Correct Use survey interval variables
   c. Matched pairs one-sample t test – to compare IDEXX Quanti-Tray® and H_2S LRVs

(3) A regression line describes the relationship between two variables (Moore et. al, 2012). Simple linear regression analysis can verify if there is a significant relationship between the Correct Use variable and filter performance.

One of the purposes of this study is to identify which Correct Use variables influence high and low performance based on LRVs, as outlined in (2) on the previous page. Therefore, it was appropriate to designate two groups for each type of log reduction value, and further investigate information associated with those filters to identify influential variables. The four groups are listed in **Table 4-3**. "Poor-performing" in this study is defined as achieving < 1 LRV. An equal number of filters in the "well-performing" group, defined as achieving > 2 LRV, were analyzed.

Table 4-3: Investigated groups based on LRV type and performance level.

Total Coliform LRV	***E. coli* LRV**
1. Well-performing (N = 20)	2. Well-performing (N =13)
3. Poor performing (N =20)	4. Poor performing (N=13)

In order to find out which Correct Use variables might affect high and low performance based on total coliform and *E. coli* LRVs, significant tests were conducted, which included the chi-square and two-sample t significance tests.

4.8.1. Significance Tests

In general, a significance test is used to compare observed data with a hypothesis. There are many tests of significance, but details described below are common to all. The accuracy of the hypothesis is evaluated in a significance test. A population parameter is described by the hypothesis. The test results can be reported in probabilities or test statistics, which are referred to as "scores." The score determines if the observed data and hypothesis agree. The first step in conducting a significance test is to establish a statement for which refuting evidence will try to be found.

The **null hypothesis**, H_o, is the statement being evaluated in a significance test. The strength of the evidence against the null hypothesis is assessed. The null hypothesis is typically expressed as "no difference in the true means" exists between the two populations (Moore et. al, 2012). For this study, the two populations examined will be both poor vs. well-performing filters based on total coliform LRV and poor vs. well-performing filters based on *E. coli* LRV. Another component of a significance test is the **alternate hypothesis**, H_a, which is the statement the researcher suspects to be true instead of the null hypothesis. The alternate hypothesis usually takes the form of "the true means are not the same" between the two populations (Moore et. al, 2012). In reference to this particular research, the alternate hypothesis would state the parameter differs from the null hypothesis in a specific direction. This is also known as the alternative hypothesis being one-sided. For example, it would be suspected that the high performing filter population exhibits a greater mean of filter cleaning frequency than the low performing population.

After calculating the test score, which measures how far the data are from the null hypothesis, the final step for conducting a significance test is to state a conclusion. The test score is compared to a fixed value that is considered decisive, which corresponds to predicting the amount of evidence against the null hypothesis needed to reject the null hypothesis. The fixed value matches to a probability called the significance level. The significance level used in this research is 0.05 or 5%, which means that it is required for the data to yield refuting evidence in relation to the null hypothesis so strong that it would happen no more than 5% of the time when the null hypothesis is true (Moore et. al, 2012). If the test score is greater than the fixed value, called the critical score in this thesis, statistical significance is reached. An alternative way to look at reaching statistical significance is if the test score is transformed to a p-value and is less than the significance level. Reaching statistical significance (from the standpoint of chi-square and two-sample t tests) means that the difference observed between two samples from the same group would only occur due to chance less than 5% of the time, therefore when one observes it here, it can be inferred that the two groups are not identical with respect to the observed variable.

There are three possible conclusions one can draw from a significance test:

(1) Variation observed between two groups is due to random chance;
(2) Variation observed between two groups is due to the variable being tested; and finally,
(3) Variation observed between two groups is due to an unknown or lurking variable.

Reaching statistical significance can rule out (1), leaving (2) and (3) as possible explanations. Interpretation is left to the author if (3) can be excluded. Therefore, this leaves (2) as the conclusion, where the variable being tested is suggested to be associated with filter performance. In other words, there might be a meaningful relationship between the observed variable and filter performance.

4.8.2. Chi-square (χ^2) Tests

The chi-square test is an appropriate significance test for comparing counts between two choices across two groups. This is particularly applicable to testing a variable from the Correct Use checklist, where the two choices would be exhibiting compliance or non-compliance. Compliance, in this thesis, is defined as the observation or reporting of the correct behavior measured by the survey variable. An example of a chi-square set up testing item #12 in the Correct Use checklist (allows turbid water to settle for at least one hour) is shown in **Table 4-4**. Details and conclusion of the significance test follows. The chi-square score was calculated using computer software available online, "*Calculation for the Chi-Square Test: An Interactive Calculation Tool for Chi-square Tests of Goodness of Fit and Independence*" (Preacher, 2010). The Yates' chi square score was considered in this analysis because the number of successes and number of failures in each group are less than five.

Table 4-4: Chi-square for Correct Use variable (allows turbid water to settle for at least one hour).

Compliance with item #12 (allows turbid water to settle for at least 1 hr.)	**Group 1**: TC LRV Well-Performing Filters (N=20)	**Group 2**: TC LRV Poor-Performing Filters (N=19)*
Yes	20	16
No	0	3

*Note: One survey respondent did not report if she was compliant or non-compliant.

Null hypothesis, H_0: There is no association between the row and column variables in a two-way table, or specifically, performance level based on TC LRV and allowing the water to settle for at least one hour are not related. In other words, distributions of compliance are the same across performance level.

Alternate hypothesis, H_a: Row and column variables are related.

Degree of freedom (df) = (number of rows – 1)(number of columns – 1) = 1; used to determine critical chi- square score below.

Critical chi-square (χ^2) score = 3.84, which corresponds to a significance level (α) = 0.05 or 5% and a degree of freedom = 1. The critical chi-square score can be found using a chi-square distribution critical values table (**Appendix F**).

Calculated Yates' chi-square (χ^2) score = 1.56; calculated using the online tool mentioned above (Preacher, 2010).

Since calculated χ^2 score < critical χ^2 score, the null hypothesis cannot be rejected and statistical significance is not attained, which means that the difference in compliance across the performance level groups could be due to chance.

If statistical significance were attained, causation would not be proven, but one can only say that the specific performance level is more likely to exhibit compliance or non-compliance, depending on the variable under consideration. Furthermore, the results of a chi-square test do not present the insight into the nature of the relationship between the two variables. If statistical significance is obtained, the chi-square test will be presented alongside the percentages of compliance and non-compliance to describe the significant relationship.

The chi-square test can also be used for more than two choices. The chi-square test is used for different variables and multiple conditions or choices as seen in the results section; however, the same principles described here are used in the same way.

4.8.3. T Significance Tests: Two-sample and Matched Pairs One-sample

The two-sample t tests were appropriate in this study to test the significance of variables that could be numerically averaged between two groups, such as ceramic pot fill frequency per day for poor and well-performing filters based on total coliform LRV. An example calculation for this specific variable is described below.

Null hypothesis, H_0 = There is no difference between the means of each population or $\mu_2 = \mu_1$, where μ represents the entire population. Since the entire population cannot be measured or surveyed, a portion or sample of the entire population is used to calculate and predict the entire population parameter. In the case of this report, the null hypothesis says the survey variable being tested does not inform filter performance.

Alternative hypothesis, H_a = The mean of population 2 is greater than that of population 1 or $\mu_2 > \mu_1$. It is expected that on average, users with poor performing filters fill the system more frequently.

X_1 = sample mean of population 1 = mean of group 1 = mean of well-performing filters based on TC LRV = 1.45 fills/day

S_1 = standard deviation of population 1 sample = 0.61

N_1 = sample size of population 1 = 20 filters

X_2 = sample mean of population 2 = mean of group 2 = mean of poor performing filters based on TC LRV = 1.88 fills/day

S_2 = standard deviation of population 2 sample = 0.89

N_2 = sample size of population 2 = 20 filters

Degree of freedom (df) = (smaller of N_1 and N_2) – 1 = 19; used to determine the critical t score below.

Critical t score = 1.729; which corresponds to a significance level (α) = 0.05 or 5% and a degree of freedom = 19. This value can be found using a t distribution critical values table (**Appendix G**).

Equation 4-3: Calculated two-sample t score (Moore et. al, 2012).

$$\text{Calculated t score (t)} = \frac{X_1 - X_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}} = |-1.77| = 1.77$$

Since the calculated t score = 1.77 > critical t score = 1.73, the null hypothesis can be rejected and statistical significance is obtained. The observed data shows that filters that performed poorly based on TC LRV filled their filter more frequently throughout the day. Because statistical significance was attained, variation due to mere chance can be excluded. Therefore, the tested variable or a lurking variable can be interpreted as exhibiting a relationship with filter performance.[2]

As seen in the results section, the two-sample t significance tests were conducted with different variables that can be numerically averaged. Although different variables were tested, the same procedure, described above, is used.

Matched pairs one-sample t tests were conducted for the special case of comparing LRVs, associated with one filter, from the IDEXX Quanti-Tray®/2000 (QT) and H_2S bacteria tests for 9 filters. The summary of data used is found in **Table 4-5** and a sample calculation is shown below.

[2] Filling frequency is not the sole variable that affects filter performance; its relation to cleaning frequency further informs the issue. More discussion on how filling and cleaning frequencies affect performance level can be found in **Section 6.4.3**.

Table 4-5: Data used for matched pairs one-sample t test.

Filter	(1) QT TC LRV	(2) H_2S LRV	(3) Experimental Δ = (1) – (2)	(4) Ideal Δ = (1) – (2)
A	1.26	2.92	-1.67	0
B	0.47	2.28	-1.81	0
C	1.38	2.59	-1.21	0
D	1.20	2.81	-1.61	0
E	- 0.15	0.82	-0.97	0
F	0.61	2.16	-1.54	0
G	5.47	2.35	3.12	0
H	0.95	1.28	-0.33	0
I	1.13	2.81	-1.69	0

Null hypothesis, H_0: There is no difference between the means of the two populations (experimental and ideal Δs).

Alternate hypothesis, H_a: There is a difference between the means of the two populations (experimental and ideal Δs).

X_3 = sample mean of column (3) = mean difference in LRVs = -0.86

S_3 = standard deviation of column (3) = 1.56

X_4 = sample mean of column (4) = 0

S_4 = standard deviation of column (4) = 0

N_3 = number of samples in column (3) = N_4 = number of samples in column (4) = 9

Degree of freedom (df) = (N_3 or N_4) -1 = 8, used to determine the critical t score below.

Critical t score =2.31; which corresponds to a significance level (α) = 0.025 or 2.5% (two-tailed) and a degree of freedom = 8. This value can be found using a t distribution critical values table (**Appendix G**).

Equation 4-4: Calculated matched pairs one-sample t score (Moore et. al, 2012).

Calculated t score = $t = \frac{X_3 - X_4}{s_3/\sqrt{N_3}} = |-1.65| = 1.65$

A significance level of 2.5% is applied in this specific scenario because the H_a states there is a difference, not a particular direction. Since the calculated t score = 1.65 < critical t score = 2.31, the null hypothesis cannot be rejected and statistical significance is not obtained. In this particular case, the researcher does not want to reject the null hypothesis, because the relationship between H_2S and QT results would like to be explored. A relationship that exhibits no difference is a significant finding and may suggest that the results from these two methods are comparable. Based on this study, on average there is no difference between the H2S and IDEXX Quanti-Tray® test results because both results seem to be centered on the same value. More discussion on this topic can be found in **Sections 5.4.1** and **6.3.**

4.8.4. Correlation and Regression

The form, direction, and strength of the relationship between two quantitative variables can be depicted in a scatter plot. Scatter plots are included in the statistical analysis (**Sections 5-4** and **5-5**). Important facts about pertinent concepts, such as correlation and regressions, are described here and are subsequently used to analyze the data in **Chapter 5**.

The strength and direction of a linear relationship between two quantitative variables is measured by the correlation, r. The value of r is between -1 and 1. If the value of r is close to 0, there is a very weak linear relationship. The closer r approaches to -1 or 1, the strength of the linear relationship increases and indicates that the points are arranged close to a straight line. It is important to note that correlation does not provide a complete description of the relationship between two quantitative variables (Moore et. al, 2012).

If a linear relationship is exhibited in a scatter plot, a line is drawn to indicate the overall pattern. This line is called a regression or trend line, which can be generated if one variable informs/predicts the other variable, i.e. explanatory and response variables. Correlation and regression are connected in many ways. A very important connection involves squaring the correlation value, r. "The square of the correlation, r^2, is the fraction of the variation in the values of y that is explained by the least-squares regression of y on x" (Moore et. al, 2012). The r^2 value indicates how successful the regression explains the response. For example if r = 0.7, and r^2 = 0.49, this indicates 49% of variation is described by the linear relationship.

Caution must be taken when interpreting the relationship between two variables because it might be the case that the relationship can only be understood by considering other overlooked or neglected variables. In other words, lurking variables can mislead a correlation or regression. Even though the observed relationship between an explanatory and response variable is strong, this alone cannot suffice to prove that changes in the explanatory variable causes changes in the response. It is also important to note that, "A correlation based on averages over many individuals is usually higher than the correlation between the same variables based on data for individuals" (Moore et. al, 2012). Regression lines are usually employed to forecast the response to the explanatory variables. However, a successful prediction does not necessarily prove cause and effect relationship. In other words, correlation does not prove causation.

In order to determine if a meaningful relationship can be predicted by the least-squares regression line $\hat{y} = b_0 + b_1x$, which can be generated from Microsoft Excel by fitting a trend line to a scatter plot, one-sided significance tests for regression slope have been conducted. Details of this significance test are described as follows.

Null hypothesis, H_0: b_1 = slope = 0; which states there is no straight-line relationship between y and x and that linear regression of y on x cannot predict y.

Alternate hypothesis, H_a: $b_1 > 0$ or $b_1 < 0$; depending on observed slope from trend line.

Degree of freedom (df) = N – 2; where N = number of samples

Critical t score = corresponds to significance level of $p = 0.05$ or 5% and degrees of freedom (df). This value can be found using a t distribution critical values table (**Appendix G**).

Equation 4-5: Calculated t score for significance test for regression slope (Moore et. al, 2012).

Calculated t test score = $t = \frac{b_1}{SE_{b_1}}$; where SE_{b1} = standard error of b_1.

The calculated t test score was determined using Microsoft Excel's regression analysis tool. If the calculated t test score > critical t score; the null hypothesis can be rejected and statistical significance is obtained. Therefore, data suggests that the regression line predicts the response variable well and there is evidence that the variables are related. In other words, a statistical significant linear relationship between the two variables was found.

Reaching statistical significance does not necessarily mean that a strong predictive relationship has been found between the variables. The confidence interval of the slope can give more insight into the relationship. If statistical significance is reached, the 95% confidence interval (CI) for the regression slope will be reported.

Moreover, it is also important to note that a larger sample size might better estimate the population regression line, but it cannot diminish the degree of scatter around the line. A strong relationship between data points can be observed, but this can be due to a small sample size, i.e. N = 2. The significance test for slope in linear regression is closely linked to the significance test for correlation, due to the fact that when the slope equals zero, so too does correlation, and vice versa. The results of a significance test for correlation, basically says if there is evidence to substantiate that correlation is not zero. A correlation of zero states there is no linear association with the population or in other words, x and y are independent (Moore et. al, 2012). The test for a zero population correlation is outlined below.

Null hypothesis, H_0: ρ = population correlation = 0; no linear association
Alternate hypothesis, H_a: $\rho > 0$ or $\rho < 0$; depending on the direction observed from the scatter plot.
r = sample correlation = determined by trend line generated by Microsoft Excel.
N = sample size
Degree of freedom (df) = N – 2, used to determine critical t- score below.
Critical t-score = corresponds to significance level (α) of $p = 0.05$ or 5% and degree of freedom (df). This value can be found using a t distribution critical values table (**Appendix G**).

Equation 4-6: Calculated t score for significance test for correlation (Moore et. al, 2012).

Calculated t-score = $t = \frac{r\sqrt{N-2}}{\sqrt{1-r^2}}$

If calculated t-score > critical t-score, the null hypothesis can be rejected and statistical significance is attained, which provides clear evidence that the x and y variables are related.

It is important to note that this type of analysis is only applicable to data that exhibit a straight-line pattern (Moore et. al, 2012). As a final statistical test, a simple regression analysis was undertaken by the author.

In this thesis, if a scatter plot is presented a summary will be followed with either $p_r<0.05$ or $p_r>0.05$ and $p_c<0.05$ or $p_c>0.05$ where:

p_r = probability found using the significance test for slope regression;
p_c = probability found using the significance test for correlation;
$p_r<0.05$ = a statistically significant linear relationship was found between the two variables;
$p_r>0.05$ = a statistically significant linear relationship was not found between the two variables;
$p_c<0.05$ = x and y variables are related; statistically significant correlation.
$p_c>0.05$ = x and y variables are not related; no linear relationship; no statistically significant correlation.

5. Results

5.1. Data Management

A total of 85 households, which received PHW's AfriClay filter, were visited during the period of January 4 to 19, 2013 in the Northern Ghanaian village of Yipelgu. The researcher administered the Correct Use survey, and collected stored and filtered drinking water samples from each household. In addition, the researcher collected samples from 13 community raw water sources. The types of sources included earthen dams, unprotected hand dugwells, a natural pond, and a river. Survey responses were recorded on paper copies during the research period. Responses were then transferred to a Microsoft Office Excel spreadsheet in order to easily manage and analyze. Summaries of these responses can be found in **Section 5.2**.

Turbidity and total coliform/*E. coli* Most Probable Number (MPN) were tested for every water sample collected. Hydrogen sulfide (H_2S) bacteria tests were conducted by a PHW technician on the untreated and treated water samples associated with 10 randomly chosen households. Only a subset of the collected samples was tested for H_2S bacteria due to the labor intensive nature of the test, but with the purpose of having a low cost cross-checking test.

IDEXX Quanti-Tray®/2000 trays were available to measure total coliform MPN and *E. coli* MPN. Dilutions from 1:10 to 1:10,000 were utilized in order to capture results in the correct range. The main focus was to capture a quantitative MPN for total coliform bacteria, as it is an indicator of, "the effectiveness of processes such as filtration or disinfection" (WHO, 2011b, p. 294). *E. coli* is an indicator of fecal contamination, which may not always be present in the untreated and treated water samples. Therefore it was determined that testing primarily to capture total coliform MPN was the most valuable parameter in ascertaining filter peformance. As a result, not all water samples have both discrete total coliform MPN and *E. coli* MPN results. However, it was usually the case that the dilution used to target total coliform also captured an *E. coli* result. Seventy-nine filters had a complete set of data (discrete MPN results for untreated and treated samples) for total coliform, 76 filters for *E. coli*, and all 85 filters for turbidity. As previously mentioned, this particular set of filters represents the first to be extensively monitored in the field rather than in PHW factory's quality control stage since the UNICEF-Ghana distribution in Yipelgu is the first large-scale distribution of PHW factory produced filters.

In the first three days of water quality testing, the researcher experimented with different dilutions to chiefly target total coliform bacteria. On a number of occasions, it was the case that multiple dilutions for one particular sample would yield quantitative results. In order to select the most representative MPN, IDEXX Technical Support suggests choosing the result associated with a dilution that exhibited 80% positive wells & 20% negative wells, also referred to as the 80/20 guideline (IDEXX Technical Support, Personal communication, March 3, 2013). Since there is a total of 97 large and small wells in an IDEXX Quanti-Tray®/2000 tray, a dilution that produced approximately or close to 78 (80%) positive wells was selected, where positive wells are yellow for total coliform bacteria and yellow/fluorescent for *E. coli*. The most representative MPN for total coliform and *E. coli* may not necessarily come from the same dilution. It was determined that after experimenting with various dilutions, a 1:100 dilution for a stored water sample and 1:10 dilution for a filtered water sample usually captured a quantitative total coliform MPN result under these particular field site conditions. These dilutions were used for subsequent collected water samples, where the 80/20 guideline did not have to be applied as frequently as compared to the first three days of testing. The 80/20 guideline was also applied to the total coliform and *E. coli* MPN/100 mL results for the 13 drinking water sources.

IDEXX Technical Support also specifies that a result of <1 MPN/100 mL and <10 MPN/100 mL can be coded to 1.0 MPN/100 mL and 5.0 MPN/100 mL respectively for statistical analysis purposes. Since it is possible to obtain a result of 1.0 MPN/100 mL and 5.0 MPN/100 mL from a dilution at the outset, the researcher coded such a result as 0.999 MPN/100 mL and 4.999 MPN/100 mL respectively to distinguish a code result from an actual result. The MPN of <1/100 mL took precedence in the situation where <10/100 mL or <100/100 mL were also obtained from 1:10 and 1:100 dilutions for the same sample, respectively, since it yields a more finite range and most representative result devoid of bias. Results of <100 MPN/100 mL and >2419.6 MPN/100 mL were not recommended by IDEXX Technical Support to be coded in any way as they would greatly skew the analysis. If the only results available were not able to be coded into a quantitative number in the format described above, the sample for the particular water quality parameter was disregarded. **Table 5.1** illustrates the transformation between a raw data set to the most representative MPN/100 mL results for total coliform and *E. coli* for stored and filtered samples associated with one household.

Table 5.1: Obtaining a discrete MPN/100 mL for total coliform and *E. coli.*

Water Quality Parameter	Stored Water Sample (1)	Tot. # of Positive Wells for (1)	Filtered Water Sample (2)	Tot. # of Positive Wells for (2)
Total coliform (MPN/100 mL)				
a. 1:1	a. 816.4	a. 84	a. 2.0	a. 2
b. 1:10	b. --	b. --	b. <10	b. 0
c. 1:100	c. 1,220.0	c. 11	c. --	c. --
E. coli (MPN/100 mL)				
a. 1:1	a. 7.4	a. 7	a. <1	a. 0
b. 1:10	b. --	b. --	b. <10	b. 0
c. 1:10	c. <100	c. 0	c. --	c. --
Most Representative MPN/100 mL				
a. Total coliform	a. 816.4		a. 2.0	
b. E. coli	b. 7.4		b. 0.999	

5.2. Survey Summary

As mentioned previously 85 filters were monitored during the research period. However, a total of 87 households were visited. Each household survey was given a number according to the order in which it was visited. One household did not receive an AfriClay filter designated as survey "C-10", while the other household not accounted for was not using the system because her children shattered the filtering element. This particular survey is known as survey "C-75".

Question #8 of the administered survey asked the direct question, "Are you using the filter?" All 85 respondents reported that they are using the system. Nevertheless, it is most likely that this is not the case; respondents may have given courtesy responses. Thus, in addition to recording self-reports, a damp or partially full filtering element was observed. Ninety-six percent of respondents displayed compliance with this Correct Use checklist item as seen highlighted in **Table 5-4**.

The following are summaries of data collected from the Correct Use surveys. The administered survey can be divided into three separate parts:

(1) General househould information and drinking water sources
(2) Filter usage data
(3) Correct Use checklist

It should be noted that not all variables were recorded for each of the 85 households with filters due to the evolution of survey questions and applicability to the respondent resulting in varying sample sizes.

5.2.1. Summary of General Household Information and Drinking Water Sources

Table 5-2: Summary of key general household and drinking water source variables.

Average number of individuals per household (n = 85)		6.3
Average number of children < 5 years old per household (n = 67)		2.0
Respondent household status (n = 85)	Housewife	76.5%
	Daughter	12.9%
	Daughter-in-law	1.2%
	Sister	1.2%
	Niece	1.2%
	Landlady	7.0%
Primary dry season water source (n = 85)	Northeast dam	61.2%
	"Fenced" dam	1.2%
	Dikunani dam	28.2%
	Southeast dam	9.4%
Secondary dry season water source (n = 58)	Northeast dam	29.3%
	"Fenced" dam	48.3%
	Wanbong dam	3.45%
	Jankun River	3.45%
	Southeast dam	5.2%
	No alternative	10.3%
Primary wet season water source (n = 85)	Unprotected dugwell # 1	78.8%
	Unprotected dugwell # 2	16.5%
	Dikunani dam	1.2%
	Covered West hand dugwells	1.2%
	Lohu hand dugwell	2.3%

Secondary wet season water source (n = 82)	Unprotected dugwell (2/2)	2.4%
	Lohu hand dugwell	1.2%
	Rainwater harvesting	8.6%
	No alternative	87.8%

Some key aspects revealed in **Table 5-2** are as follows. The researcher initially inquired about the total number of children in each household for the first two days of field research covering 18 households. It was determined that a more pertinent question would be to ask how many children ≤ 5 years old live in this household as this population is critical in diarrheal disease incidence. Therefore, this modified question was asked during the remaining 67 surveys, where it was found that an average of 2 children ≤ 5 years old live in each household.

Table 5-2 shows that the majority of the survey respondents were housewives and daughters. This can also be visually seen in **Figure 5-1** below.

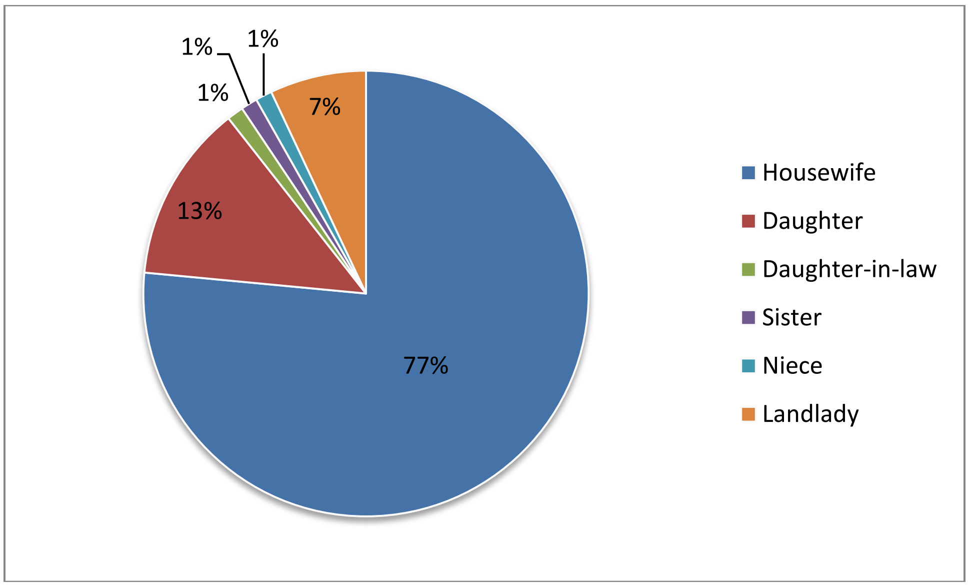


Figure 5-1: Household status (n = 85).

The main primary dry season drinking water sources are the Northeast Dam and Dikunani Dam as seen in **Figure 5-2**. If the respondent reported that their respective dry season water source was available throughout the entire season, a secondary dry water source was not recorded. The same approach was applied to the secondary wet season drinking water source. Since the researcher visited Yipelgu during the dry season, the relevant water sources cited above were the main focus, and samples were collected accordingly.

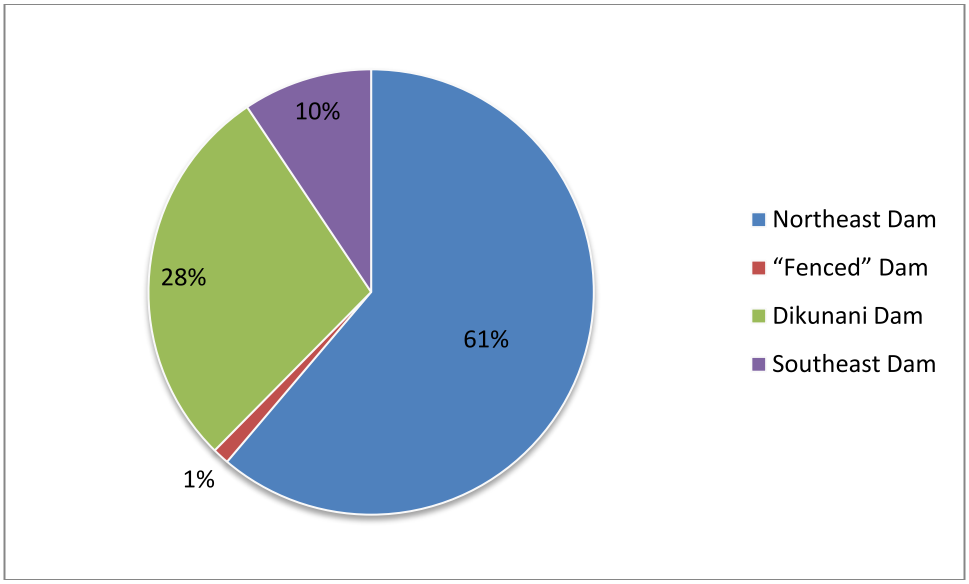


Figure 5-2: Primary dry season water source (n = 85).

5.2.2. Summary of Filter Usage Data

Table 5-3 summarizes key general variables related to filter usage; not included in the table are cited reasons for not using the filter, where there were only two cases (C-72 and C-75) in which there were responses to this question. One of those two respondents stated that the system requires a long period of time to filter the untreated water. The second case reported that she does not use the filter at all since her children have broken the filtering element.

Table 5-3: Summary of key general filter usage variables.

Duration of filter ownership (n = 85)	1 month	51.8%
	2 months	48.2%
Is the filter easy to use? (n =85)	Yes	97.6%
	No	2.4%
Difficulties of filter use (n =85)	Easily broken by children	1.2%
	Clogs easily	1.2%
	Intensive maintenance	3.5%
	Small in size	2.3%
	Assembling tap after cleaning	1.2%
	None	90.6%
Improvements (n = 52)	Faster flow rate	52.0%
	Larger system	3.8%
	Child-proof tap	1.9%
	Faster flow rate & larger system	5.8%
	No improvements when asked	36.5%
Fill frequency per day (n= 85)		1.7
Reasons for cleaning filter (n = 85)	Stops filtering (1)	8.2%
	Low flow rate (2)	1.2%
	Dirty filtering element (3)	58.8%
	Dirty safe storage container (4)	1.2%
	(1) & (2)	2.35%
	(1) & (3)	14.1%
	(2) & (3)	1.2%
	(3) & (4)	9.4%
	(1), (3), & (4)	2.35%
	Other	1.2%
Frequency of cleaning filter (n = 85)	Daily	7.0%
	Every 2 days	27.1%
	Every 3 days	51.8%
	Every 4 days	5.9%
	Weekly	8.2%
Correct description of proper cleaning method (n = 85)		100%
Filter problems (n = 85)	Tap leakage	4.7%
	Tap leakage & low flow rate	1.2%
	None	94.1%
Replacement parts needed (n = 86)	Yes	2.3%
	No	97.7%

When respondents were asked if there are any difficulties associated with the filter, the majority answered that there was no such trouble. Again, courtesy responses may have played a role. However, when respondents were then asked the question if they can recommend any improvements to the filter, they were more vocal in their opinions. The overwhelming response for suggested improvements was a faster flow rate as seen in **Figure 5-3**.

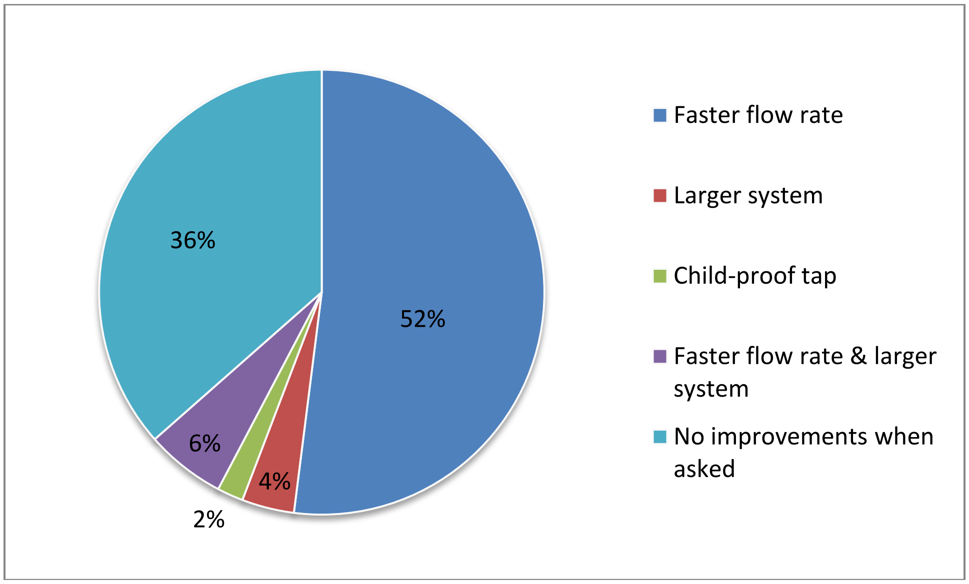


Figure 5-3: Suggested improvements (n = 52).

As for reasons for cleaning filter, respondents could cite multiple reasons. The percentages for combinations of cleaning reasons are described separately in **Table 5-3**, 5th section from the bottom. A dirty filtering element was found to be the main reason for cleaning.

Impressively, all 85 surveys correctly described the cleaning method for the filter system. This suggests that the training sessions effectively conveyed the cleaning procedure. In regards to filter problems, five cases of tap leakage were reported, two of which were fixed by the time of the survey (C-2 and C-74), two were mitigated while the survey was conducted (C-72 and C-78), and one case still exhibited leaking even though the researcher thoroughly checked washer alignment and loose connections (C-52). The tap mechanism itself was concluded to be the cause of the problem, and therefore a replacement tap was provided. The second case where a replacement part was needed, involved a broken filtering element (C-75).

5.2.3. Summary of Correct Use Checklist

Table 5-4: Summary of compliant surveys (as %) that exhibit correct use checklist items (n = 85).

	Correct Use Checklist	
Assembly	1. All components are present	100.0%
	2. Ceramic pot installed in the plastic safe-storage unit	100.0%
	3. Ceramic pot's rim fully covers the top rim of the safe storage container	97.6%
	4. CPF system components rest evenly on each other	80.0%
	5. CPF system is on level surface	84.7%
	6. CPF system on prescribed stable base	34.1%
	7. Base is approximately 1 foot high	82.4%
	8. Tap extends beyond edge of base	97.6%
	9. Tap shows no signs of leaking; washers are in proper sequence	96.5%
	10. CPF system located against a wall, not in middle of room	100.0%
	11. CPF system located out of direct sunlight	100.0%
Treatment	12. Turbid water undergoes settling for at least one hour before filtration	94.0%
	13. Ceramic pot is partially full or at least damp	**96.5%**
	14. Ceramic pot is not overfilled. Water level remains below lip of pot	98.7%
	15. Storage unit is not filled above the bottom of the ceramic pot	100.0%
Demonstration	a. Used cup or calabash to scoop water from large settling container to fill filter	98.8%
	b. Cup or calabash used to fill filter is hygienic	85.2%
	c. Cup or calabash used to access filtered water is hygienic and located near filter	70.7%
	d. Filtered water is served directly from tap	100.0%
	e. Nozzle of tap is not being touched while dispensing filtered water	92.7%
	f. Sample collected safely (not touching water with hands)	100.0%
Safe Storage	17. There is water in the safe-storage unit	100.0%
	18. Lid kept in place and is securely covered, except when being filled	100.0%
	19. Safe-storage unit is clean inside and out	87.1%
	20. Out of reach of possible contaminant sources	69.4%
Maintenance	21. Ceramic pot, storage unit, and tap are clean	61.2%
	22. Ceramic pot, storage unit, and tap show no visible leaks or cracks	96.5%
	23. Safe storage unit shows no signs of stress	95.3%
	24. Respondent never uses soap or disinfectant with the ceramic pot itself	100.0%
	25. Instructional sticker intact on filter	81.2%

Table 5-4 reviews the percentage of respondents that were able to demonstrate or self-report the Correct Use item (#1-25). The items that had the lowest percentage of compliance were 6, 20, and 21. Almost all items were determined based on the authors observations except items 12, 18, and 24 were verbally answered by the respondent.

5.3. Yipelgu Drinking Water Sources

Table 5-5: Summary of community drinking water source water quality data.

Drinking Water Source	**Total coliform (MPN/100 mL)**	***E. coli* (MPN/100 mL)**	**Turbidity (NTU)**
Southeast Dam	**6,700**	**310**	**231**
Northeast Dam	7,380	310	85
Dikunani Dam	7,520	410	609
Covered West hand dugwell	10,140	8,090	147
Jankun River	12,010	860	81
Wanbong Dam	13,340	850	529
"Waterlilies" Dam	20,100	1000	53
Pond	23,300	2,000	76
"Fenced" Dam	30,500	10,900	185
Unprotected dugwell with hand pump	30,900	<1000	159
Lohu hand dugwell	36,540	3,640	59
Watering hole	43,500	5,200	290
Unprotected hand dugwell (near Lohu)	54,750	520	154

Table 5-5 shows total coliform/*E. coli* (MPN/100mL) and turbidity of all the 13 drinking water sources tested in the village of Yipelgu. **Table 5-6** gives the ranges of the source water quality

parameters. There is a wide variability in terms of total coliform, *E. coli*, and turbidity levels between the community water sources.

Table 5-6: Summary of water quality parameter ranges for village water sources (n = 13).

Water Quality Parameter	Source Water Range
Total coliform (MPN/ 100 mL)	6,700 – 43,500
E. coli (MPN/ 100 mL)	310 – 10,900
Turbidity (NTU)	53 – 609

The ranges of water quality parameters tested for stored water samples (**Table 5-7**) do not exactly reflect the results in **Table 5-6**, which is likely due to particulate settling, recontamination, and bacterial die off or growth.

Table 5-7: Summary of water quality parameter ranges for stored samples (n = 85).

Water Quality Parameter	Source Water Range
Total coliform (MPN/ 100 mL)	488– 2,419,600
E. coli (MPN/ 100 mL)	1 – 19,040
Turbidity (NTU)	13 – 1000

The most representative MPN and NTU value from **Table 5-5** was linked to each individual stored water sample through the respondent's reporting of the primary dry season drinking water source. Pre-treatment occurs between the time of source water retrieval and filling the filtering element, which consists of sedimentation measured by turbidity and bacterial die off measured by total coliform and *E. coli*. As seen in **Table 5-8**, pre-treatment can contribute to the overall filter performance level. Sample sizes included in **Table 5-8** are a subset of the total sample size (n = 85) because negative log reduction values and negative % removals were disregarded in this specific analysis. A possible explanation for these negative values may be due to the time of day the researcher collected the source water samples, the sampling location, and/or incorrect reporting of household primary drinking water source. Collection time and sampling location affect the most representative source water MPN and NTU values because turbidity and bacterial densities vary throughout the day, and are also dependent on the specific locality.

Table 5-8: Summary of water quality parameters; comparing source water to stored water.

Water Quality Parameter	No. of samples (n)	Minimum	Maximum	Median	Arithmetic Mean	Geometric Mean*	Standard Deviation
Total coliform LRV	33	0.0	1.2	0.2	0.4	0.3[a]	0.4
E. coli LRV	51	0.0	2.5	0.5	0.6	0.5[b]	0.6
Turbidity % Removal	41	0.5	89.1	41.8	42.1	31.3[c]	24.6

*Samples size for geometric mean may be less than that of other statistical summarizing factors since zero values are disregarded. [a] Sample size (n) = 25. [b] Sample size (n) = 45. [c] Sample size (n) = 41.

5.4. Overall Ceramic Hemispheric Filter Performance

Table 5-9: Risk level categories (WHO & UNICEF, 2012).

Level of *E. coli* Contamination	**WHO Risk Level**
< 1 CFU/100 mL	No action required
1 – 10 CFU/100 mL	Low risk
11 – 100 CFU/100 mL	Intermediate risk
101 – 1000 CFU/100 mL	Very High
> 1000 CFU/100 mL	Very High [*sic*]

Table 5-9 reviews the risk levels adopted for the subsequent analysis of overall filter performance (**Figures 5-4** to **5-6**). These risk levels are applied to MPN results and NTU levels in this study, even though WHO and UNICEF (2012) apply them only to *E. coli* contamination. Colony forming units (CFU) provide an actual count of bacterial colonies, while Most Probable Number (MPN) represents a statistical estimate.

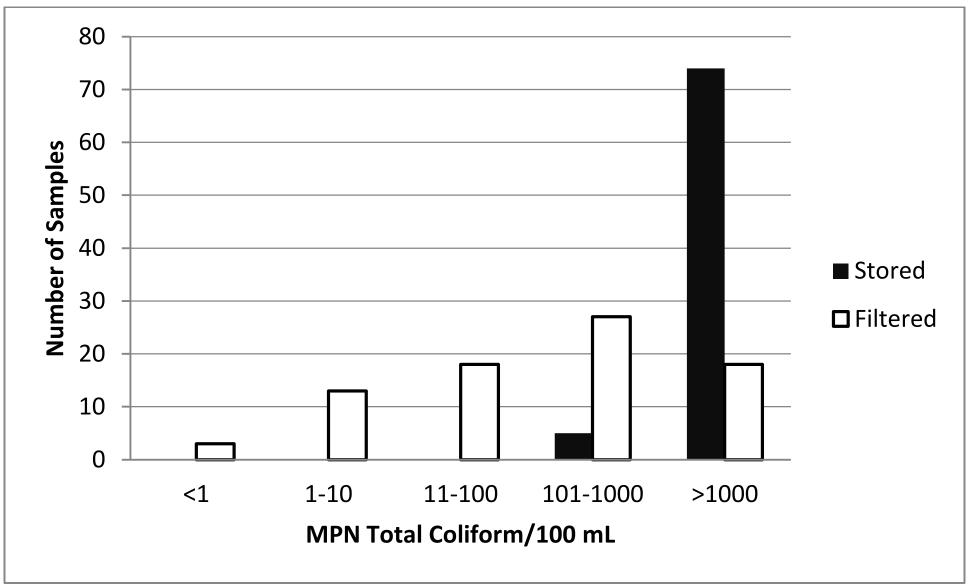


Figure 5-4: Comparison of total coliform concentrations by range category in stored vs. filtered water samples (n = 79).

As shown in **Figure 5-4**, the total coliform concentrations for the majority of the stored samples exhibited > 1000 MPN/100 mL. After filtration, concentrations > 1000 MPN/100 mL significantly decreased from 74 to 18 samples. A shift towards lower risk categories is evident.

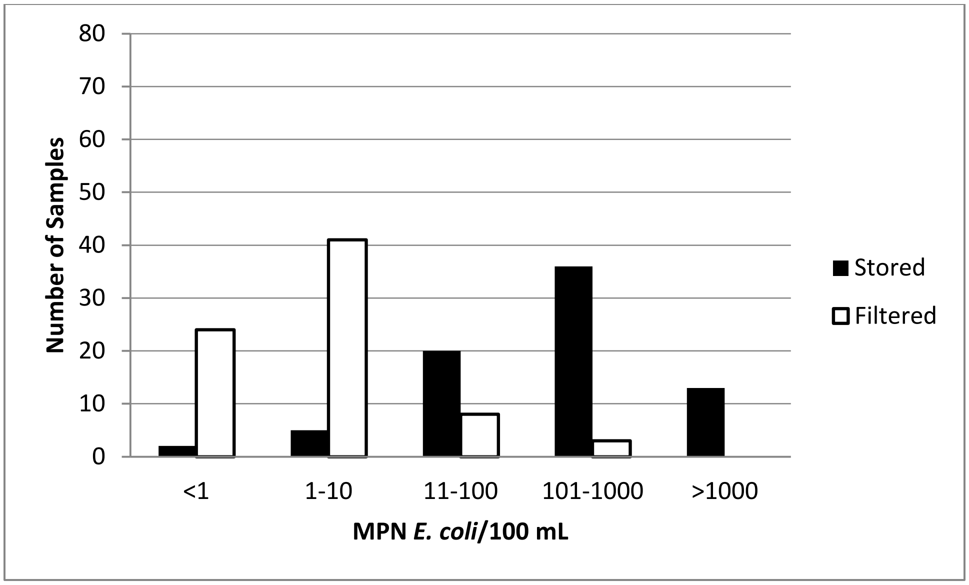


Figure 5-5: Comparison of *E. coli* concentrations by range category in stored vs. filtered water samples (n = 76).

A similar trend can be seen in **Figure 5-5** in regards to *E. coli* concentrations, i.e. a greater shift towards lower risk categories for filtered vs. stored water.

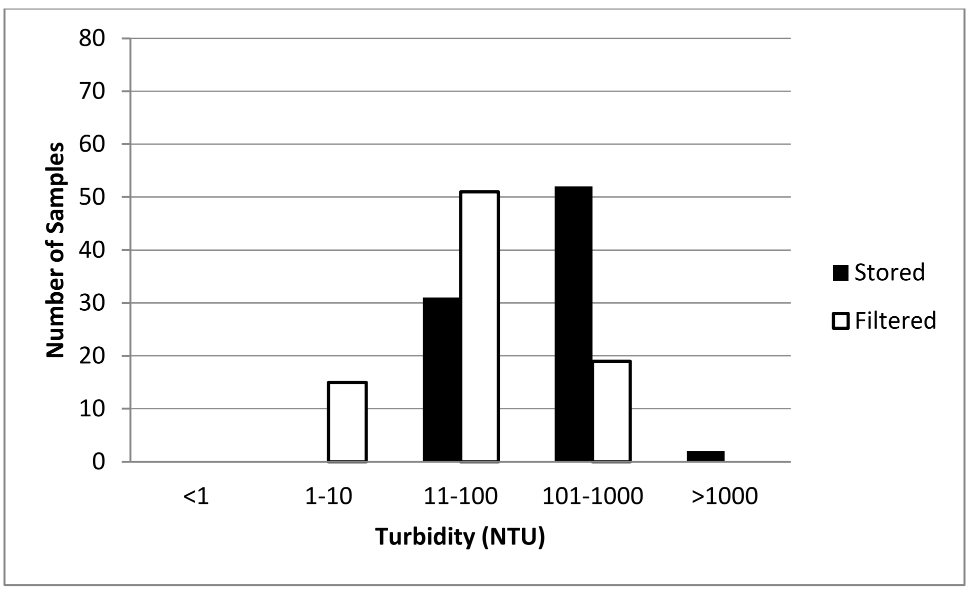


Figure 5-6: Comparison of turbidity values by range category in stored vs. filtered water samples (n = 85).

Fifty-four stored water samples had turbidity values greater than 100 NTU (**Figure 5-6**). The number of filtered samples in these two ranges (101 – 1000 and >1000 NTU) decreased, while samples with 11-100 NTU values increased. Due to the extremely high turbidity levels of source water, only 3 filtered samples met WHO and UNICEF's (2012) recommendation of <5 NTU for drinking water.

Table 5-10: Geometric means of total coliform, *E. coli*, and turbidity

Water Quality Parameter	Stored Sample	Filtered Sample
Total coliform (MPN/ 100 mL)	12,905 (9,162-18,197)	141 (78.7-253.5)
95% Confidence interval	*(N = 81)*	*(N = 83)*
***E. coli* (MPN/100 mL)**	202 (133-308)	4 (3-5)
95% Confidence interval	*(N = 76)*	*(N = 85)*
Turbidity (NTU)	157 (122-201)	40 (31-51)
95% Confidence interval	*(N = 85)*	*(N = 85)*
% Total coliform reductions[a]	**--**	99
% E. coli reductions[a]	**--**	98
% NTU reductions[a]	**--**	80

[a] Calculated as $\log_{10}$ reduction = $\log_{10}$ influent – $\log_{10}$ effluent and subsequently the $\log_{10}$ reductions were transformed into percentages.

Table 5-10 summarizes the geometric means of stored vs. filtered water quality parameters, i.e. total coliform, *E. coli*, and turbidity. It is appropriate to calculate the geometric mean, rather than the arithmetic mean, for bacterial data since it is typically not normally distributed, but rather is often skewed. In order to obtain approximate normal results, the data should be transformed to its logarithmic value, which is taken into account when calculating the geometric mean (APHA, 2012). The geometric mean prevents a few higher values from overestimating higher levels of contamination, which could be the case if one uses the arithmetic mean (Gerba, 2009). As seen in the table above, the ceramic hemispheric filter exhibited improvements in drinking water quality based on total coliform, *E. coli*, and turbidity (99%, 98%, and 80% removals respectively).

The WHO's *Evaluating Household Water Treatment Options: Health-based Targets and Microbiological Performance Specifications* presents a tiered approach in establishing levels of performance (**Table 5-11**). The performance of the ceramic pot filter can be measured up to this evaluation framework. There are three recommended performance levels for bacteria, virus, and protozoa reduction based on disability-adjusted life years (DALYs) and projected as log reduction values (LRVs). For the target of bacteria, a technology that exhibits a LRV ≥ 4 is considered performing at a "highly protective" performance level and LRV ≥ 2 represents a protective level. In this study, the "interim" target as specified in **Table 5-11** will be modified to represent $1 \leq x < 2$ $\log_{10}$ reduction for bacteria. In order to evaluate PHW's AfriClay filter, log reduction values for total coliform, *E. coli*, and turbidity were calculated and analyzed as follows.

Table 5-11: Derivation of targets (WHO, 2011a).

Target	$\log_{10}$ reduction required: **Bacteria**	$\log_{10}$ reduction required: **Viruses**	$\log_{10}$ reduction required: **Protozoa**
Highly protective	≥ 4	≥ 5	≥ 4
Protective	≥ 2	≥ 3	≥ 2
Interim*	Achieves "protective" target for two classes of pathogens and results in health gains		

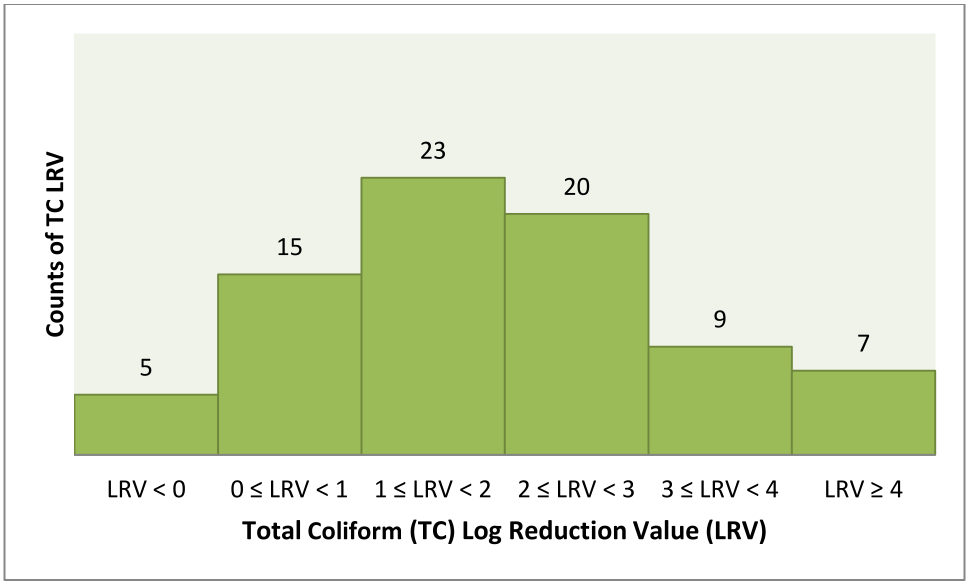


Figure 5-7: Comparison of total coliform (TC) log reduction values by range category (n=79 filters).

Table 5-12: TC LRV summary.

Total Coliform Log Removal Value Summary	
Minimum (n = 79)	-0.68
Maximum (n = 79)	5.47
Median (n = 79)	1.92
Arithmetic mean (n = 79)	1.95
Geometric mean* (n = 74)	1.70
Standard deviation (n = 79)	1.33

*LRVs ≤0 were disregarded in order to calculate the geometric mean, which accounts for the smaller sample size of 74 rather than 79.

Fifty-nine filters out of the 79 filters tested for total coliform safely achieved a log reduction value (LRV) ≥ 1, 36 of which reached a LRV ≥ 2 (**Figure 5-7**). This first mass distribution of PHW's AfriClay filter generally achieved a LRV ≥ 1, but not consistently ≥ 2 LRV. Twenty filters performed at ≤ 1 LRV, and 7 filters performed exceptionally well at ≥ 4 LRV. In terms of WHO's health-based household water treatment performance targets for bacteria, 46% of the filters demonstrated protective standards (≥ 2 LRV) and 9% exhibited highly protective levels (≥ 4 LRV), for a total of 55% falling into the protective or highly protective categories. Twenty-nine percent of monitored filters performed in the range of 1 ≤ x < 2 LRV, falling into the interim category.

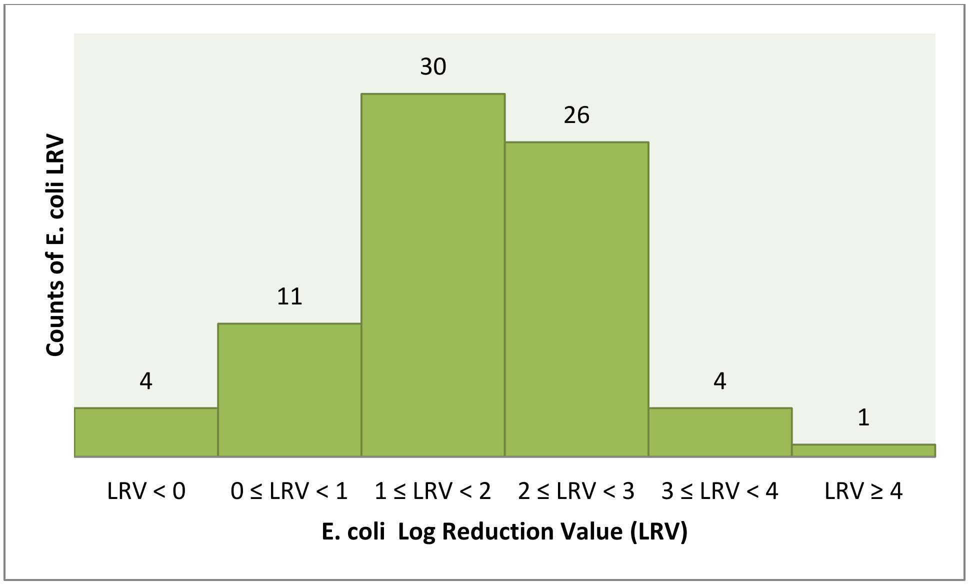


Figure 5-8: Comparison of *E. coli* Log Reduction Values by range category (n=76 households).

Table 5-13: *E. coli* LRV summary.

***E. coli* Log Removal Value Summary**	
Minimum (n = 76)	-0.50
Maximum (n = 76)	4.28
Median (n = 76)	1.90
Arithmetic mean (n = 76)	1.74
Geometric mean* (n = 70)	1.73
Standard deviation (n = 76)	0.91

*LRVs ≤0 were disregarded in order to calculate the geometric mean, which accounts for the smaller sample size of 70 rather than 76.

As seen in **Figure 5-8,** 61 out of the 76 filters analyzed for *E. coli* achieved ≥ 1 LRV, 31 of which obtained ≥ 2 LRV. The majority of filters performed in the range of 1 – 2 LRV. Fifteen filters performed poorly with results ≤ 1 LRV, and 1 filter performed at ≥ 4 LRV. With regards to the health-based household water treatment performance targets for bacteria, 41% of the filters demonstrated protective standards (≥ 2 LRV) and 1% exhibited highly protective levels (≥ 4 LRV). A total of 42% of filters performed at a protective or highly protective level, while 39% performed at the interim level.

The filter performance based on total coliform bacteria LRV's and *E. coli* LRV's exhibit similar patterns with a few performing at the extremes and the majority achieving 1 to 2 LRV.

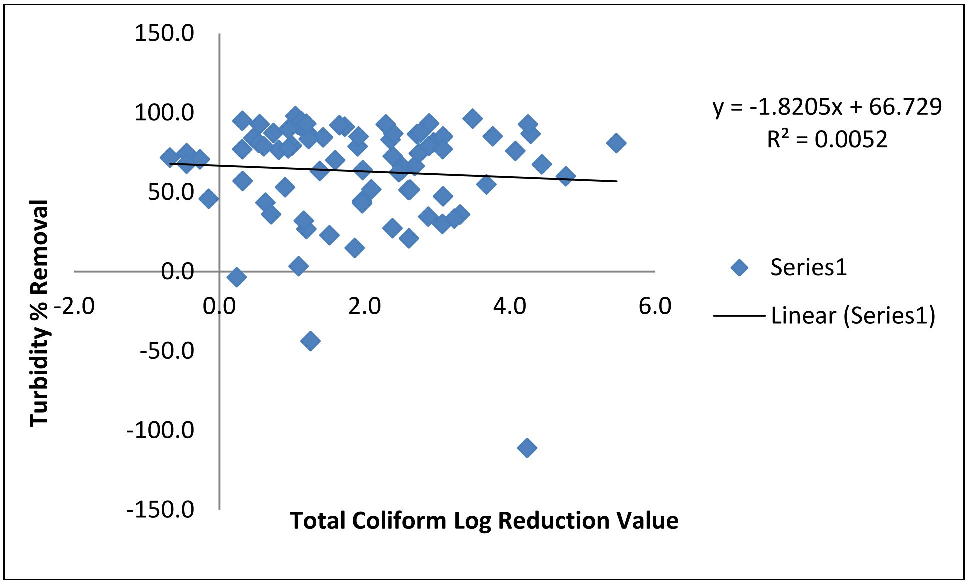


Figure 5-9: Turbidity removal (%) vs. total coliform log reduction values (n = 79 surveys).

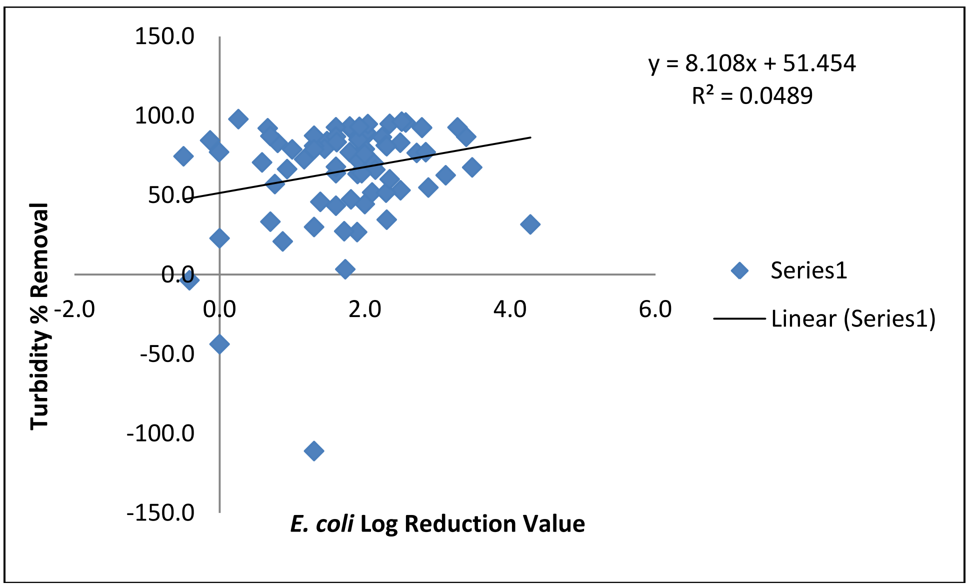


Figure 5-10: Turbidity removal (%) vs. *E. coli* log reduction values (n = 76 surveys).

Figure 5-9 shows the lack of a statistically significant linear relationship ($p_r > 0.05$) and lack of statistically significant correlation ($p_c > 0.05$) between % turbidity removal and total coliform log reduction values. The variables of *E. coli* log reduction values and % turbidity removal in **Figure 5-10** were found to exhibit a statistically significant linear relationship ($p_r < 0.05$) and statistically significant correlation ($p_c < 0.05$). The 95% confidence interval (CI) for its slope is (-0.17, 16.39), which represents that an increase of 1 *E. coli* log reduction value is associated with an increase in % turbidity removal between -0.17 and 16.39. Removing suspended particles can increase the removal of bacteria that are attached to the solids. The trend line exhibited in **Figure 5-9** does not follow the expected pattern altogether, while the trend line in **Figure 5-10** adheres to the correct direction and attains statistical significance. The discrepancy exhibited in

Figure 5-9 might be due to the different indicator bacteria, distribution of the bacteria within the sample, and/or recontamination of the treated water (Yang et. al). Another possible explanation may derive from the IDEXX Quanti-Tray® test detection for total coliform. This issue is further discussed in **Section 6.5**.

5.4.1. H_2S Bacteria Test Results

As already mentioned in **Section 5.1**, only a subset of the filters was tested for H_2S bacteria.[3] Nine out of the ten filters tested for H_2S bacteria were compared to the respective total coliform and *E. coli* results achieved from IDEXX Quanti-Tray®/2000 test.[4] **Figures 5-11** to **5-13** show no statistically significant correlations ($p_r > 0.05$, $p_c > 0.05$), as calculated by the appropriate significance tests, between the paired data sets from two test methods, H_2S bacteria and IDEXX Quanti-Tray®.

It was hypothesized that H_2S bacteria test results, could possibly correlate with IDEXX's MPN method, but that was not found to be the case. The H_2S bacteria test, as its name suggests, detects bacteria that produces H_2S, such as *Salmonella, Proteus, Citrobacter, Edwardsiella*, and some species of *Klebsiella* which are associated with fecal contamination (Hach Company, 1997). The lack of statistically significant correlation in this case could be due to different groups of indicator bacteria, different media, dissimilar testing procedures, measurement errors, and/or technician errors. Bacterial densities must also be considered in evaluating microbiological test results. If a sample with low bacterial densities is split into two, it will be less likely for both split samples to test positive than if the sample possessed higher bacterial densities, which can be attributed to the inherent statistical variation in bacterial densities between samples. This is applicable to all microbiological tests (Yang et. al).

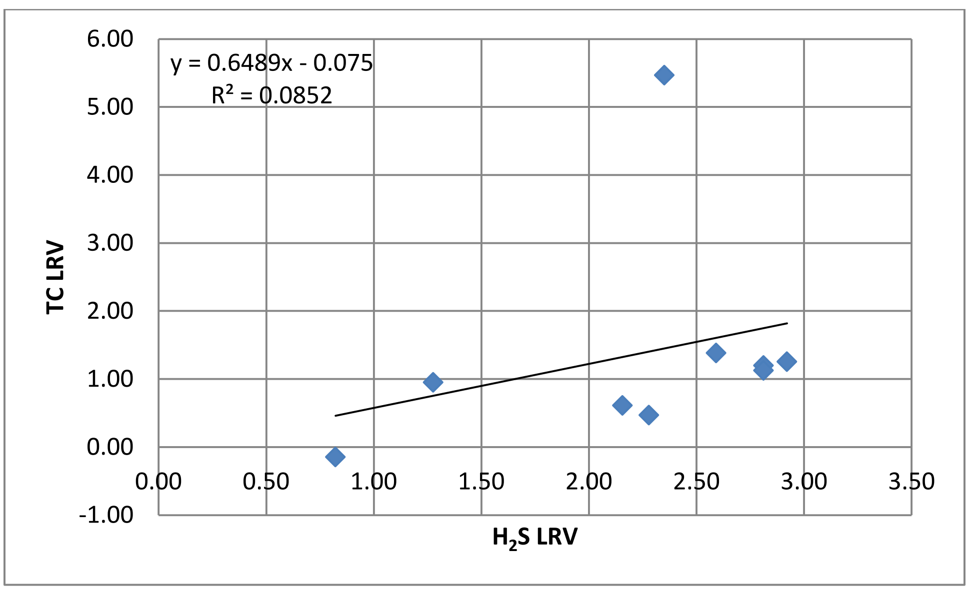


Figure 5-11: TC log reduction value vs. hydrogen sulfide bacteria log reduction value (n=9 filters).

[3] The assistance of PHW staff, Abdul-Karim Alale and Peter Atuba, in conducting H_2S tests is appreciated. The author conducted the corresponding IDEXX Quanti-Tray®/2000 tests.
[4] One filter was omitted from comparison because the log reduction values could not be calculated from total coliform and *E. coli* results that were too numerous to count (TNTC).

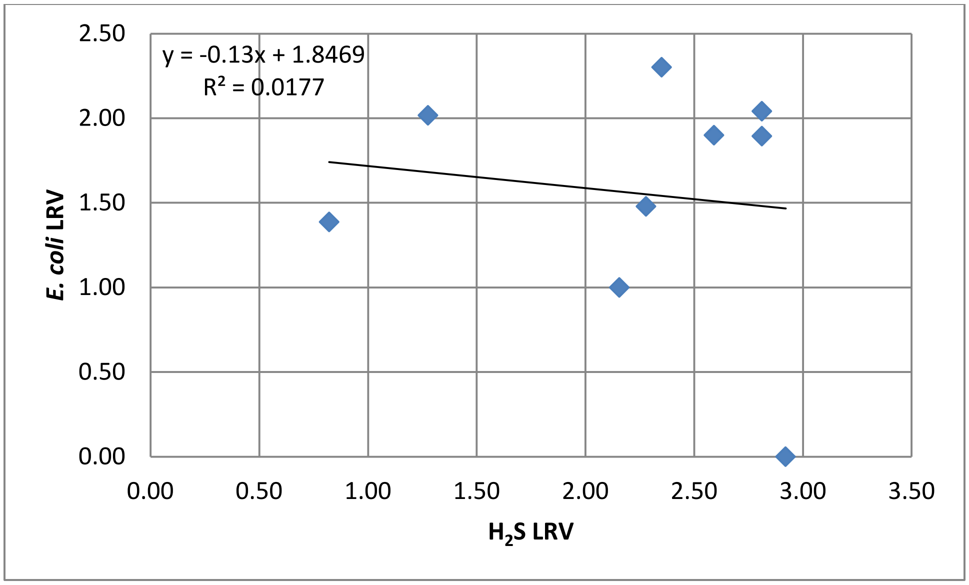


Figure 5-12: *E. coli* log reduction value vs. hydrogen sulfide bacteria log reduction value (n=9 filters).

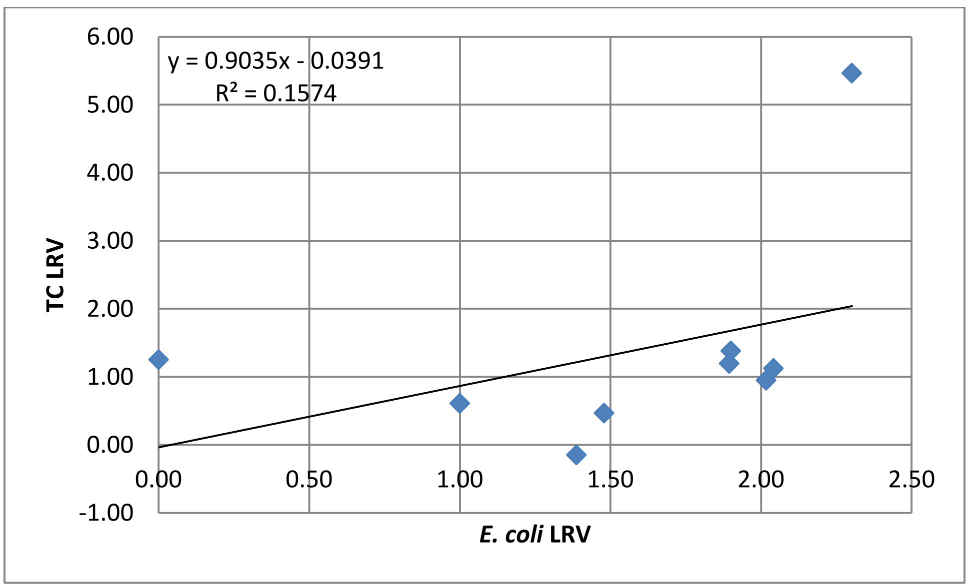


Figure 5-13: Total coliform log reduction value vs. E. coli log reduction value (n=9 filters).

To further investigate if the H_2S bacteria test is related to the standard IDEXX Quanti-Tray®, thresholds of 1 LRV and 2 LRV were superimposed on **Figures 5-11** and **5-12**. Establishing thresholds can verify if IDEXX Quanti-Tray® and H_2S bacteria results generally agree within a certain LRV range. Thresholds of LRV's 1 and 2 were chosen because they are of particular interest since PHW aims for the filtering element to exhibit at least LRV 1 of total coliform or *E. coli* without an application of colloidal silver, and at least 2 LRV with the colloidal silver.

In other words, if a threshold of 1 LRV was designated for IDEXX Quanti-Tray® (QT) total coliform (TC) LRV and for H_2S LRV, the specific points on the scatter plot in **Figure 5-11** can be evaluated with respect to this threshold. Therefore, if the overriding majority of points correspond to the analogous relationship between both methods (IDEXX Quanti-Tray® and H_2S bacteria tests) the H_2S test results can be considered to relatively agree with QT results. **Figure 5-14** depicts establishing 1 LRV thresholds for QT TC and H_2S LRVs. This plot shows the layout of the points falling above and below the thresholds. Similar plots can be generated for different threshold levels and water quality parameters.

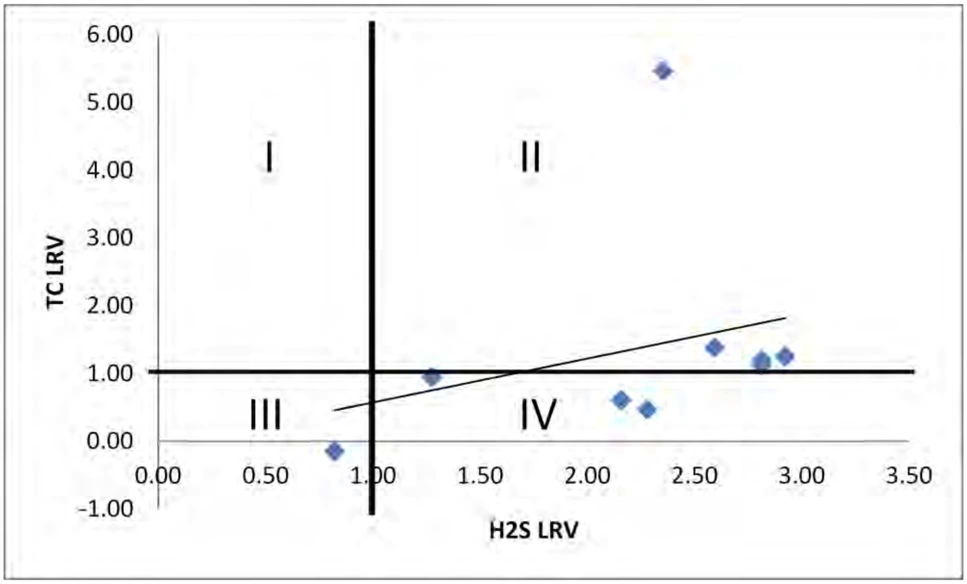


Figure 5-14: Example of establishing thresholds of 1 LRV for QT TC and H_2S LRVs.

If a threshold of 1 LRV for both QT TC and H_2S is established, 5 points lie in the area that predicts both QT TC LRV>1 and H_2S LRV>1 (Area **II** on **Figure 5-14**). One instance corresponded to QT TC LRV<1 and H_2S LRV<1 (Area **III** on **Figure 5-14**). And 3 cases corresponded to QT TC LRV<1 and H_2S LRV>1 (Area **IV** on **Figure 5-14**), where the methods do not agree with each other and signifies over-reporting from the H_2S test.

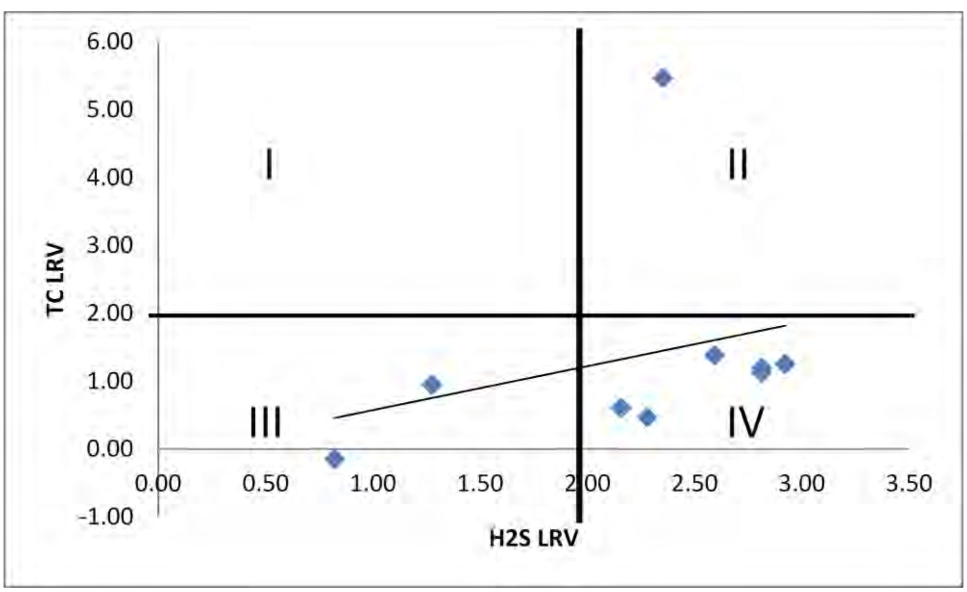


Figure 5-15: Example of establishing thresholds of 2 LRV for QT TC and H_2S LRVs.

If a threshold of 2 LRV is established for QT TC and H_2S, 1 case matched QT TC LRV>2 and H_2S LRV>2 (Area **II** on **Figure 5-15).** Two points agreed with QT TC LRV<2 and H_2S LRV<2 (Area **III**), while 6 cases corresponded to QT TC LRV<2 and H_2S LRV>2 (Area **IV**). In this particular study, the H_2S bacteria LRV better matches the standard method if a lower threshold (1 LRV) is implemented based on the larger number of points exhibiting analogous relationships across both methods. However, this cannot be considered a definite statement or rule as a small sample size of only 9 filters were able to be evaluated. Implementing a threshold of 1 LRV for IDEXX Quanti-Tray® total coliform and 2 LRV for H_2S (**Figure 5-16**), slightly improves counts of matches for QT TC LRV<1 and H_2S LRV<2 (Area **III**) compared to that of QT TC LRV<1 and H_2S LRV<1 (Area **III** in **Figure 5-14**).

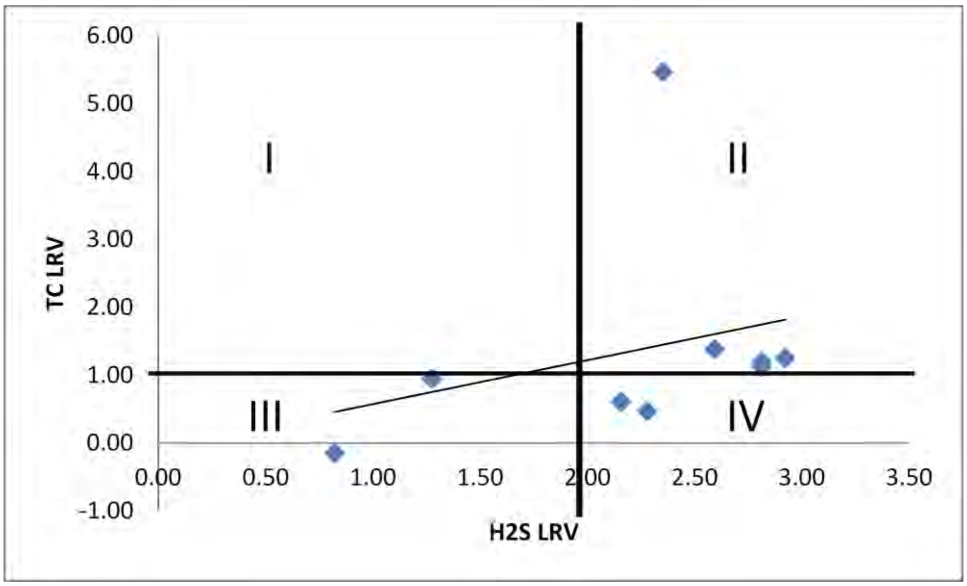


Figure 5-16: Example of a 1 LRV threshold for QT TC and a 2 LRV threshold for H_2S.

The same investigation was undertaken for **Figure 5-12**. For a threshold value of 1 LRV for both QT *E. coli* LRV and H_2S LRV, 7 cases corresponded with QT *E. coli* LRV>1 and H_2S LRV>1. One case fell into the category of QT *E. coli* LRV>1 and H_2S LRV<1, while another case exhibited QT *E. coli* LRV<1 and H_2S LRV>1. For a threshold value of 2 LRV, 2 cases matched QT *E. coli* LRV>2 and H_2S LRV>2, while 1 case matched QT *E. coli* LRV<2 and H_2S LRV<2. Similarly, 5 cases exhibited a relationship of QT *E. coli* LRV<2 and H_2S LRV>2, while 1 case exhibited QT *E. coli* LRV>2 and H_2S LRV<2. Therefore in this particular study, a lower threshold (1 LRV) yielded more counts of analogous relationships, however it still must be noted that the small sample size under consideration prevents generalization. A combination of different LRV thresholds did not yield better results in comparison to the uniform thresholds stated above.

The investigation of establishing different LRV thresholds for QT TC vs. H_2S LRVs and QT *E. coli* vs. H_2S LRVs yielded some agreement, but an overwhelming conformity was not exhibited. Therefore, a qualitative rule in predicting H_2S in relation to QT results cannot be determined.

Table 5-14: Log reduction values (LRVs) of QT and H_2S Bacteria tests (n = 9).

Filter	(1) QT TC LRV	(2) QT *E. coli* LRV	(3) H_2S LRV	(4) Actual Δ = (1) – (3)	(5) Actual Δ = (2) – (3)	(6) Ideal Δ = (1) – (3) = (2) – (3)
A	1.26	0	2.92	- 1.67	-2.92	0
B	0.47	1.48	2.28	- 1.81	-0.80	0
C	1.38	1.90	2.59	- 1.21	-0.69	0
D	1.20	1.89	2.81	- 1.61	-0.92	0
E	- 0.15	1.39	0.82	- 0.97	0.57	0
F	0.61	1.00	2.16	- 1.54	-1.16	0
G	5.47	2.30	2.35	3.12	-0.05	0
H	0.95	2.02	1.28	- 0.33	0.74	0
I	1.13	2.04	2.81	- 1.69	-0.77	0

To complete the statistical analysis comparing the IDEXX Quanti-Tray®/2000 MPN and H_2S Bacteria MPN tests, matched pairs one-sample t tests were performed in order to determine if there is a significant difference between the results. The respective LRVs achieved in each test are listed in the columns 1, 2, and 3 of **Table 5-14**. Column 6 represents the ideal change in LRVs exhibited between QT LRV (either TC or *E. coli*) and H_2S LRV. The ideal change is where there is no difference. The matched pairs t test will verify if the mean actual change (column 4 or column 5) is, on average, different from the ideal change (column 6).

First, the QT TC and H_2S LRVs were compared, where the significance test concluded that there is no statistically significant difference between the actual average change in LRVs (column 4) and the ideal average change (column 6). The same procedure was applied to QT *E. coli* and H_2S LRVs, where the significance test concluded that there is no statistical significant difference between the actual average change in LRVs (column 5) and the ideal average change (column 6). From the results of the two significance tests summarized above, there is no statistically significant difference between QT (TC or *E. coli*) with H_2S LRVs on average. Therefore, H_2S LRVs are relatively centered around the same value of QT TC and *E. coli* LRVs. In other words, if the "true" LRV calculated from a stored and filter sample was hypothetically 2.3 LRV, then both QT and H_2S results would be approximately around this value. A definite range around the "true" value cannot be determined due to the small sample size. However, from column 4, H_2S LRV's are generally observed to be a magnitude of 1.6 LRV away from QT TC LRV. From column 5, H_2S LRV's are about a magnitude of 1 LRV from QT TC LRV's.

5.5. Correct Use Summary Survey and Correlation to Water Quality Results

Since a wide range of filter performance was demonstrated, the results from the Correct Use survey, particularly the Correct Use checklist, were initially analyzed to inform filter performance variability. An unweighted Correct Use score was first calculated for 85 survey respondents. As **Figures 5-17** and **5-18** depict, the unweighted Correct Use scores with either total coliform or *E. coli* LRVs do not exhibit statistically significant linear relationships (p_r > 0.05) and lack statistically significant correlations ($p_c > 0.05$). It was hypothesized that setting up a weighted scale was might yield a more favorable linear relationship and correlation; however, this was also not the case as seen in **Figures 5-19** and **5-20**. The weighted Correct Use score gave more importance to the checklist items pertaining to treatment, demonstration, and safe storage categories. A weighting multiplication factor of 1 signifies “required,” 2 is “recommended,” and 3 is for “critical” items, which is summarized in **Table 5-15**.

Table 5-15: Unweighted vs. weighted Correct Use score.

Category	Unweighted Multiplication Factor	Weighted Multiplication Factor
Assembly	1	1
Treatment	1	3
Demonstration	1	3
Safe Storage	1	3
Maintenance	1	2
Total Number of Points	30	63

Table 5-16: Unweighted and weighted Correct Use score summary (n = 85).

Parameter	Unweighted Score (%)	Weighted Score (%)
Minimum	71.4	68.4
Maximum	100.0	100.0
Median	90.0	92.1
Average	89.9	90.7
Standard Deviation	5.9	6.3

Table 5-17: Unweighted and weighted Correct Use score counts (n = 85).

Class*	Unweighted Score Counts	Weighted Score Counts
60-69%	0	1
70-79%	4	5
80-89%	25	25
90-100%	56	54

*Rounded to the nearest whole percentage

As **Tables 5-16** and **5-17** show, there are only slight differences between the unweighted and weighted Correct Use scores for the 85 surveys. Therefore selecting a preference between the scoring systems is not necessary. The unweighted Correct Use score will be used as the default hereinafter.

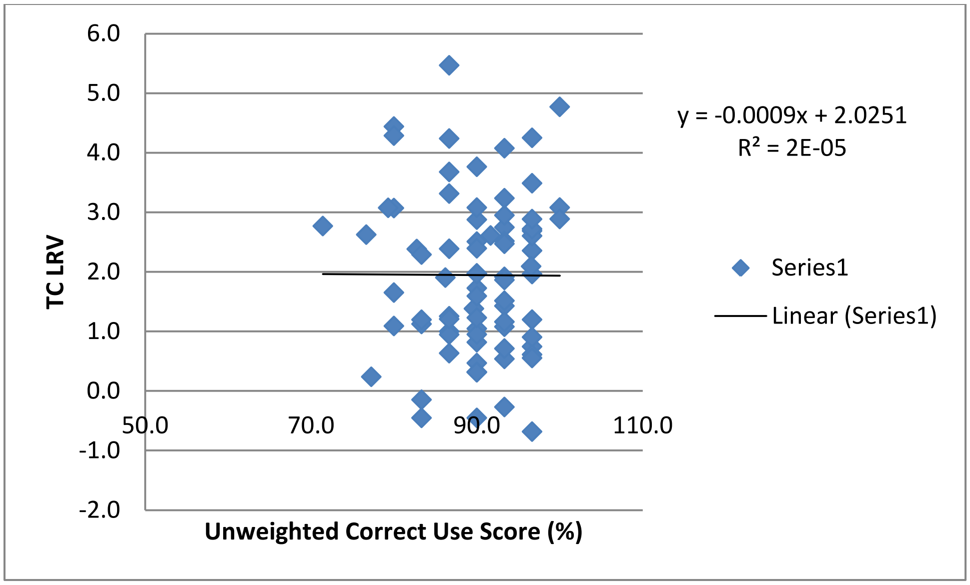


Figure 5-17: Lack of statistically significant linear relationship and correlation between total coliform LRV and unweighted Correct Use score (n = 79).

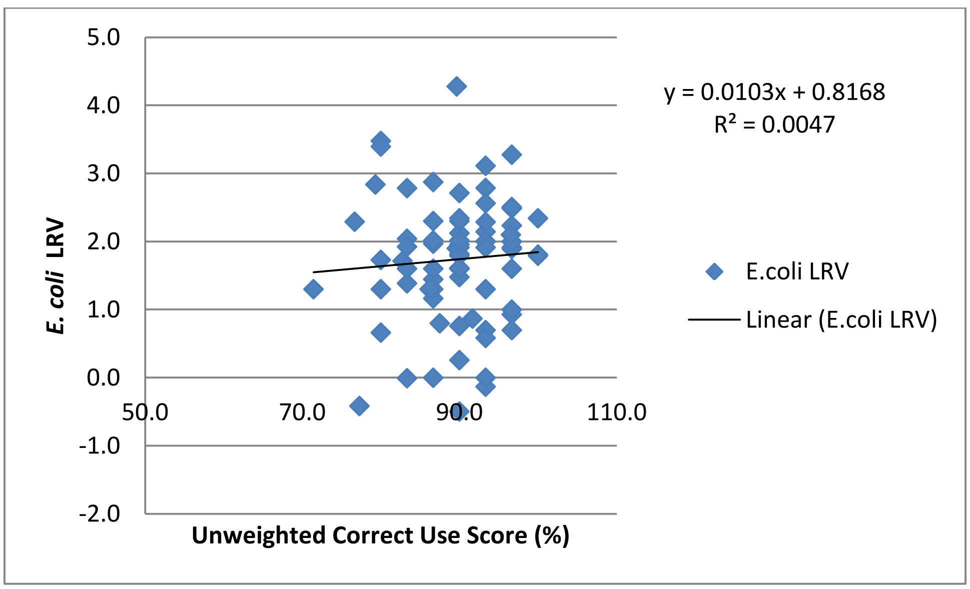


Figure 5-18: Lack of statistically significant linear relationship and correlation between *E. coli* LRV and unweighted Correct Use score (n = 76).

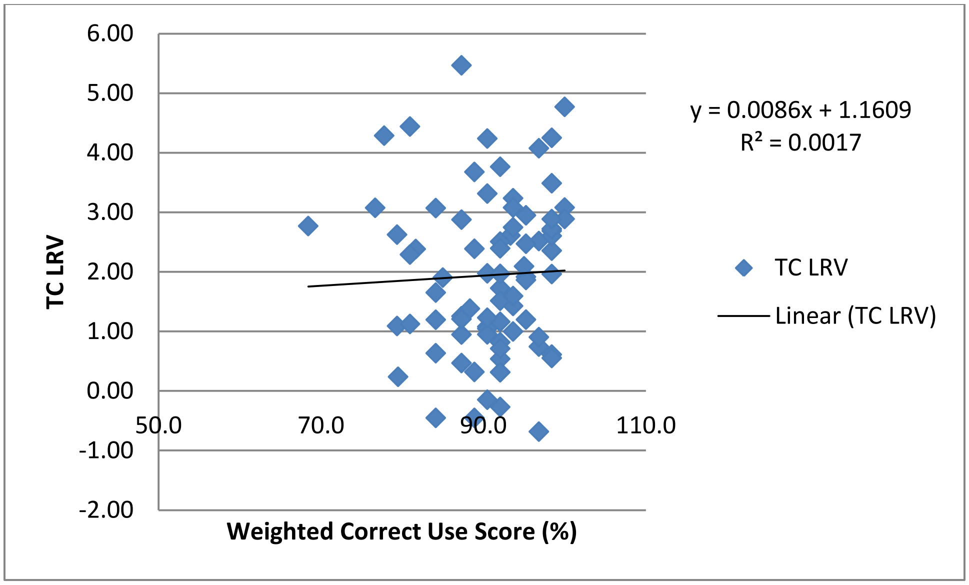


Figure 5-19: Lack of statistically significant linear relationship and correlation between total coliform LRV and weighted Correct Use score (n = 79).

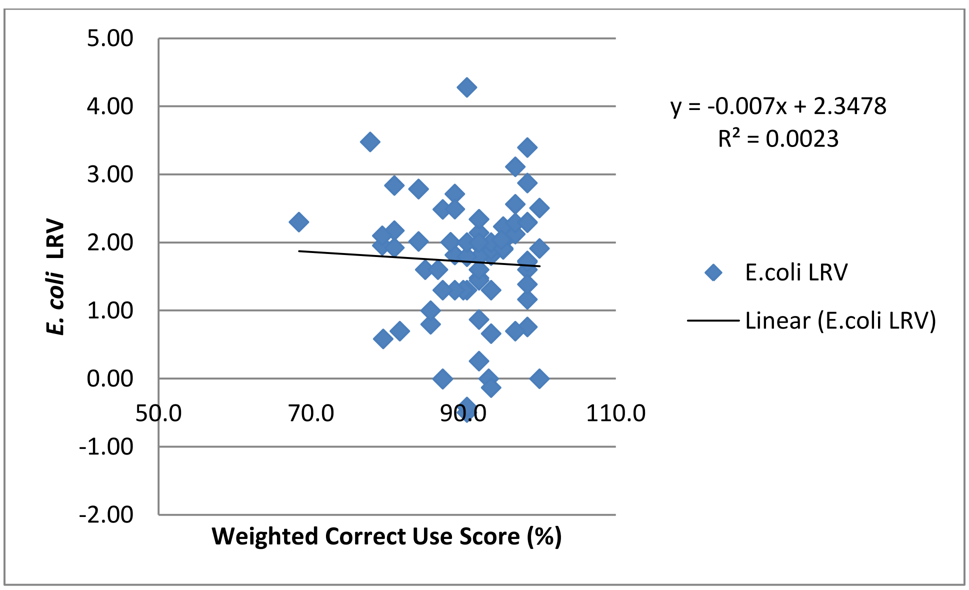


Figure 5-20: Lack of statistically significant linear relationship and correlation between *E. coli* LRV and weighted Correct Use score (n = 76).

Due to the fact that neither the unweighted nor weighted Correct Use scores exhibited a significant linear relationship and correlation with filter performance, the researcher took an alternative approach to investigate items listed in the Correct Use checklist contributing to poor and well-performing filters by concentrating on specific parameters rather than weighing or combining many variables. This alternative approach is described below. Ultimately, the chi-square test and two-sample t significance tests were conducted to determine pertinent factors that may influence the filter's performance.

Twenty filters that exhibited a "poor" performance level of < 1 total coliform LRV were investigated, while an equal number of filters in the "well-performing" group with at least a level of performance of total coliform LRV > 2 served as the comparison. The averages of every Correct Use item from the checklist were calculated for each group. The difference of each response between both groups was taken. If the difference between the responses is zero or close to zero, it is unlikely that the particular variable under consideration is related to a difference in performance. However, if a large difference is exhibited there is the possibility that the difference between these two groups is related, and a significance test should be conducted.

Since the Correct Use checklist cannot be numerically averaged due to the fact that it only has 'yes' or 'no' responses, as well as taking into account the fact that the overall number of observations was small, the chi-square test for significance was deemed the most appropriate. The Yates' chi-square score was considered in this analysis since the number of successes and the number of failures in each group is less than 5. Critical chi-square or t test scores are reported rather than their respective probabilities in order to maintain transparency in obtaining levels of significance. The same procedure was conducted for 13 filters that performed at a poor and well-performing level based on *E. coli* LRV. Results of these tests are found in **Tables 5-18** and **5-19**. The author did not analyze a larger number of surveys within each group since it would be more meaningful to designate only poor-performing filters as achieving a LRV < 1, because an unpainted filtering element should obtain a LRV of at least 1 upon leaving the PHW factory. If more surveys were analyzed, opposing groups would start to resemble one another and outstanding intricacies would be concealed. This would occur because if a larger sample size was considered for each group then the definition of poor and well-performing filters would broaden. Therefore, performance levels would be closer – defeating the purpose of analyzing what influences low and high LRVs.

Table 5-18: Total coliform LRV Correct Use checklist investigation (n = 20).

Checklist Item	Calculated chi-square	Critical chi-square score[a]	Statistically Significant
#3 Pot rim fully covers safe storage unit	0	> 3.84	No
#7 Base is approx. 1' high	0	> 3.84	No
#12 Settling stored water for more than 1 hour	1.56	> 3.84	No
#16B Uses hygienic filling vessel	0.14	> 3.84	No
#19 Clean safe storage container	0	> 3.84	No
#21 Pot, storage unit, tap are clean	0.40	> 3.84	No

[a] Critical chi-square score corresponds to the degrees of freedom (df) = (r-1)(c-1), in this case df = 1, and level of significance of p = 0.05.

Table 5-19: *E.coli* LRV Correct Use checklist investigation (n = 13).

Checklist Item	Calculated chi-square	Critical chi-square score[a]	Statistically Significant
#4 CPF system components rest evenly on each other	0	> 3.84	No
#5 CPF system is on level surface	0	> 3.84	No
#6 Prescribed stable base	0	> 3.84	No
#7 Base is approx. 1' high	0	> 3.84	No
#16B Uses hygienic filling vessel	0.01	> 3.84	No
#16C Drinking cup is hygienic & near filter	0.17	> 3.84	No
#16E Tap nozzle is not being touched	0.30	> 3.84	No

[a] Critical chi-square score corresponds to the degrees of freedom (df) = (r-1)(c-1), in this case df = 1, and level of significance of p = 0.05.

The chi-square result for item #12 of the Correct Use checklist achieved the highest chi-square score (**Table 5-18**). Since the comparison of means test did not show reason to investigate this variable in the *E. coli* LRV group (**Table 5-19**), the *E. coli* results are therefore found in **Table 5-20**. The results in **Table 5-20** show that since statistical significance was not obtained, the difference in observed performance can be due merely to chance.

Table 5-20: Comparison of chi-square score for item #12 across TC LRV & *E. coli* LRV.

Water Quality Parameter	Calculated chi-square score	Critical chi-square score	Statistically Significant
TC LRV	1.56	> 3.84	No
E. coli LRV	0.01	> 3.84	No

Furthermore, responses from the general survey between filters that performed at a poor and well-performing level were examined. The same surveys analyzed for the Correct Use checklist in each corresponding group based on water quality parameter and performance level were studied. In the same manner as analyzing the Correct Use checklist variables, the comparison of means was performed and a large difference implied that the variable may influence the filter's performance level. Since these responses could be numerically quantified, the two-sample t significance test was used. Results from these significance tests can be found in **Tables 5-21** and **5-22**.

Table 5-21: Total coliform LRV general survey investigation (n = 20).

General Survey Question	Calculated t score [a]	Critical t score [b]	Statistically Significant
Ceramic pot fill frequency per day	-1.77	> 1.729	**Yes**
Filter cleaning frequency	0.40	> 1.729	No
Total number of household members that use the filter	-0.35	> 1.729	No
Total number of adults that use the filter	0.25	> 1.729	No
Total number of children that use the filter	-0.71	> 1.729	No
Duration of filter ownership	-1.95	> 1.729	**Yes**

[a] The absolute value of the calculated t-score is compared to the critical t-score.
[b] Critical t score corresponds to the degrees of freedom (df) = n - 1, in this case df = 19, and level of significance of p = 0.05.

Table 5-22: *E. coli* LRV general survey investigation (n = 13).

General Survey Question	Calculated t score [a]	Critical t score [b]	Statistically Significant
Ceramic pot fill frequency per day	-1.27	> 1.782	No
Filter cleaning frequency	-1.63	> 1.782	No
Total number of household members that use the filter	0.18	> 1.782	No
Total number of adults that use the filter	-0.21	> 1.782	No
Total number of children that use the filter	0	> 1.782	No
Duration of filter ownership	-0.19	> 1.782	No

[a] The absolute value of the calculated t-score is compared to the critical t-score.
[b] Critical t score corresponds to the degrees of freedom (df) = n - 1, in this case df = 12, and level of significance of p = 0.05.

The variables of "ceramic pot fill frequency per day" and "duration of filter ownership" reached statistical significance when comparing the total coliform LRV or the poor and well-performing groups. Therefore, this statistical evidence is support for a reason to further investigate these variables.

Figure 5-21 depicts total coliform log reduction values vs. fill frequency per day for filters considered in both poor and well-performing groups (n = 40). The direction of the trend line shows that the more a beneficiary fills the filtering element per day; a lower total coliform log reduction value will be achieved. However, after conducting significance tests for regression slope and correlation, there was found to be no statistically significant linear relationship ($p_r > 0.05$) and lack of statistically significant correlation ($p_c > 0.05$). Even through visual inspection, the points depicted in **Figure 5-21** exhibit a wide range of variability and non-descriptive relationship. Therefore, there is reason to suspect that other or lurking variables are contributing to filter performance, even though statistical significance was obtained using the t test in **Table 5-21**. These "other" variables may have not been tested during the survey or if they had been tested did not reach statistical significance due to a small sample size (n = 40). The variable of "fill frequency per day" may be related to the "frequency of cleaning" variable. A summary of its significance test can be found in the Discussion and Recommendations chapter.

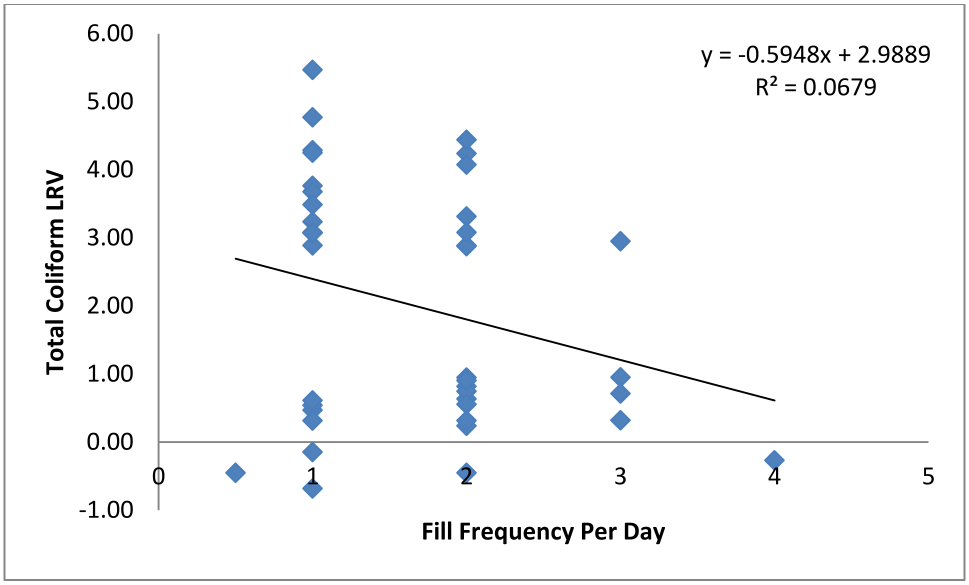


Figure 5-21: Total coliform log reduction value vs. fill frequency per day (n = 40).

The variable of "duration of filter ownership" reached statistical significance as shown in **Table 5-21**, which implies that owning the filter for a longer period of time is associated with a decrease in total coliform LRV. Although the "duration of filter ownership" was posed as an open-ended question, at the time the survey was conducted the only possible answers were 1 or 2 months given the relatively recent distributions. Therefore, the chi-square test would be better suited to test the significance of this variable, "duration of filter ownership," as seen in **Table 5-23**. Even so, statistical significance is not obtained, meaning "duration of filter ownership" may not directly influence the filter performance level.

Table 5-23: Chi-square comparison of TC & *E. coli* LRV for filter ownership duration.

Water Quality Parameter	Calculated chi-square [a]	Critical chi-square score [b]	Statistically Significant
TC LRV	2.53	> 3.84	No
E. coli LRV	0	> 3.84	No

[a] Critical chi-square score corresponds to the degrees of freedom (df) = (r-1)(c-1), in this case df = 1, and level of significance of p = 0.05.

Since only one of the variables hypothesized to affect filter performance met a level of statistical significance ($p = 0.05$), a summary of possible patterns and relationships from the remaining general survey responses between poor versus well-performing filters based on total coliform and *E. coli* LRVs is presented below. The remaining general survey responses were ultimately investigated to achieve a thorough inspection of possible variables that may influence the filter's performance.

Household status was defined as "relation to the head of the compound, i.e. housewife, sister, niece, daughter, or landlady," was not found to be of statistical significance using the chi-square test across both groups (poor and well performing filters) within the two categories (total coliform and *E. coli* LRV). The most frequent status was housewife in households for each group.

The month of which the filter was produced also did not reach statistical significance using the chi-square test in regards to filter performance based on total coliform and *E. coli* LRV. A larger study is recommended in order to adequately test the significance of the month of filter production as there are a relatively large number of variables (months) for a small sample size (n = 20 or 13). Data used in this particular test is summarized in **Table 5-24**.

Table 5-24: Counts of filters produced in a given month.

Performance Level	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	N/A*
TC Poor (n =20)	1	1	8	3	4	0	3	0	0	0	0
TC Well (n=20)	1	3	6	1	3	0	2	1	1	1	1
E. coli Poor (n =13)	1	1	3	3	1	0	2	1	1	0	0
E. coli Well (n=13)	0	2	2	2	5	0	0	1	0	0	1

*Note: A few filters did not have a serial number.

A summary of reasons, as reported from the respondents falling in either of the four groups (TC Poor, TC Well, *E. coli* Poor, and *E. coli* Well), for not using the filter and difficulties associated with filter usage are noted in **Table 5-25**. A single survey respondent (C-72), where her filter's performance fell into the poor performing group based on total coliform LRV, reported that she does not use the filter as much since the filtration process is time consuming. In regards to the portion of the general survey administered inquiring about the difficulties associated with the filter, one respondent (C-3) mentioned that her children can easily break the system. Ambiguously, this particular survey fell into both groups of well-performing based on *E. coli* LRV and poor-performing filters based on total coliform. One survey respondent (C-53), whose filter met a poor total coliform LRV level, indicated that the system involves too much maintenance. During another survey (C-31), where a filter was categorized as performing well based on total coliform LRV, a respondent pointed out that the system does not provide enough water and a larger filter would mitigate this difficulty. The remaining surveys within each group did not reveal any other difficulties.

Even though there were not many difficulties recorded (only 3 respondents from total number of respondents in the 4 groups based on water quality parameter and performance level reported difficulties), a number of improvements were suggested. The synopsis of the respondents' recommendations is as follows. (Note that when the respondent was asked about improvements, it was posed an open-ended question where multiple answers could be recorded for each individual).[5] The suggested improvement of a faster flow rate was the overwhelming response across all groups as seen in **Table 5-25**.

[5] Moreover, some individuals within each group were not asked about improvements at all because the addition of the question transpired approximately after 21% of the total number of surveys was conducted.

Table 5-25: Suggested improvements as % of total responses within each specified group.

Group	Faster Flow Rate	Larger System	Child Proof Tap	No improvement when asked
TC LRV Well (n=20)	57.1%	0%	7.1%	35.8%
TC LRV Poor (n=20)	80.0%	6.7%	0%	13.3%
E. coli LRV Well (n=13)	72.7%	0%	9.1%	18.2%
E. Coli LRV Poor (n=13)	71.4%	14.3%	0%	14.3%

The suggested improvements appear to have no relationship to whether or not the filter performed poorly or well. This shows criteria that a future researcher or public health professional may use to evaluate performance is not necessarily what the user considers important.

Table 5-26: Percents of surveys within each group, which cited reason(s) for cleaning.

Group	Stops Filtering (1)	Low Flow Rate (2)	Dirty Ceramic Pot (3)	Dirty Storage Container (4)	Other (5)	(1) & (2)	(1) & (3)	(1) & (4)	(3) & (4)
TC LRV Well (n=20)	0%	0%	60.0%	5.0%	0%	0%	25.0%	0%	10%
TC LRV Poor (n=20)	10%	5.0%	75%	0%	0%	5.0%	5.0%	0%	0%
E. coli LRV Well (n=13)	7.7%	0%	53.8%	0%	7.7%	7.7%	23.1%	0%	0%
E. Coli LRV Poor (n=13)	7.7%	0%	53.8%	0%	0%	7.7%	15.4%	15.4%	0%

Table 5-26 shows the percentage of surveys that cite specific reason(s) for cleaning the AfriClay filter system within each performance group associated with its respective water quality LRV. Multiple answers could apply to a given survey. The "other" response was recorded (C-64) as the respondent cleaning the filter for the "welfare of the filter." This presumably entails maintaining the filter's functionality, so it is probably associated with the reason of "stops filtering." The response of "dirty ceramic pot" had the highest percent value across all the groups.

In investigating recorded filter problems within the four groups (listed in **Table 5-27**), only 3 surveys reported and/or the researcher observed a filter issue. Within the group of poor performing filters based on total coliform log reduction values, one respondent (C-52) is currently experiencing trouble with the filter tap leaking and another respondent (C-72) complained of past tap leakage, in addition to a very slow flow rate at present time. For the household with the current tap leakage problem at the time of the survey, the researcher and PHW staff member ensured that the washers and tap head were correctly assembled, but the tap continued to leak. Therefore for this filter system a tap replacement was provided. The third instance (C-2) where a filter problem was reported consisted of tap leakage; however, this issue was mitigated before the time of the survey. This particular filter is categorized as poor performing based on *E. coli* LRV.

Table 5-27: Surveys investigated under specified groups.

TC LRV Poor-performing (<1)	E. coli LRV Poor-performing (<1)	TC LRV Well-performing	E. coli LRV Well-performing
C-3	C-2	C-17	C-3
C-6	C-4	C-27	C-12
C-11	C-5	C-28	C-48
C-26	C-9	C-30	C-49
C-29	C-11	C-31	C-50
C-33	C-13	C-36	C-64
C-37	C-14	C-42	C-73
C-39	C-37	C-45	C-79
C-43	C-43	C-46	C-82
C-47	C-46	C-50	C-83
C-49	C-59	C-55	C-85
C-52	C-60	C-57	C-86
C-53	C-61	C-65	C-87
C-58		C-69	
C-59		C-79	
C-60		C-80	
C-63		C-82	
C-66		C-85	
C-72		C-86	
C-81		C-87	

Table 5-28: Counts of overlapping surveys across specified groups.

TC LRV Poor & *E. coli* LRV Poor	TC LRV Well & *E. coli* LRV Well	TC LRV Poor & *E. coli* LRV Well	TC LRV Well & *E. coli* LRV Poor
4	6	2	1

Table 5-27 shows the specific surveys under consideration for each specified group based on water quality parameter and performance level. **Table 5-28** displays the counts of overlapping surveys between the specified groups. It is expected for the same performing groups between the TC and *E. coli* groups to possess overlapping surveys because *E. coli* is a subset of total coliform bacteria. However, on the contrary, some surveys were grouped in different performance levels.

As shown in **Table 5-27**, 2 surveys performed poorly in regards to TC LRV, but performed well based on *E. coli* LRV. Another overlapping survey is shown to be a part of the well-performing filter group based on TC LRV and poor-performing filter group based on *E. coli* LRV. This can be attributed to recontamination after filtration, the inherent nature of bacteria, and/or the sensitivity of MPN testing method. As per telephone communication with IDEXX Technical Support, IDEXX Quanti-Tray®/2000 is EPA certified for testing *E. coli* in surface waters, but not for total coliform. Therefore background microorganisms can affect the total coliform results, but *E. coli* test results are a more reliable measure when using this test. Furthermore, Technical Support stated that total coliform is not necessarily derived from human or animal feces and present naturally in the environment (IDEXX Technical Support, Personal communication, March 3, 2013).

6. Discussion and Recommendations

This UNICEF-Ghana distribution represents the first mass distribution of filters manufactured at PHW's own factory. Therefore, the set of filters studied during the research period is the first to be comprehensively monitored and evaluated in households. The Correct Use survey and water quality results from this field study are promising and show progress in drinking water protection in the Northern Ghanaian village of Yipelgu. This section discusses the results further and also presents recommendations that may assist in Pure Home Water's future ventures.

6.1. Further Survey Considerations and Future Mitigation

All 85 households, self-report filter usage in response to a direct survey question. This resulted in a completely unrealistic compliance rate of 100%. It was observed that 96.5% of respondents (n = 85) had a damp or partially filled ceramic pot at the time of the survey. However, because the survey team spent 3 full weeks in Yipelgu on a daily basis (the team's presence was well-known), it could have been the case that the respondent filled the filtering element just prior to the researcher's arrival. It was difficult or impossible to obtain the true number of filter users due to the fact that the community knew the survey team was monitoring the filters, and this surely increased the courtesy responses and/or apparent use of the filter.

Perhaps one way to avoid this would be to convey to the households/users that the survey team is not solely interested in the filter. Even though it may be the case that the respondent adopts the technology in order to please the researcher; the outside attention towards the filter can bring more awareness to the individual and community as a whole in its importance and possibly increase the number of filter users. A pre-testing period is recommended to assess survey questions to mitigate or eliminate courtesy responses, address translation issues, and add/remove relevant survey variables. In order to gauge the actual number of filter users, a longitudinal study should be conducted that can not only monitor Correct Use, but also Consistent and Continuous Use.

Future survey efforts should place more emphasis on asking an indirect question such as, "can you show me where you store your drinking water and/or do you treat your drinking water?" or an observation of the filter, i.e. damp or partially filled filtering element. Better still, PHW can pilot and potentially implement an objective measure, which is called a "digital flow-time device" which monitors flow through the filter's tap mechanism. Preliminary work on such a devise is reported on in Chapter 6 of Lu (2012).

General Survey Responses and Insights

Insights from survey responses can inform future surveys Pure Home Water undertakes, as well as filter design and training documentation. An important insight from the survey was the reasons for not using the filter and the need for replacement parts. If the user cannot readily obtain a replacement part, such as a tap fixture of ceramic filtering element, the use of the filter system will be discontinued. A possible solution is for a PHW employee to visit the community periodically, with the replacement parts to distribute the necessary components. Another solution could involve designating a community member to stockpile replacement parts, so the community can easily access the supply. This situation can be implemented as a business model supply chain or on a subsidized basis.

From the survey results, the major product design improvement was for a faster flow rate. If the flow rate was considered too slow by the user, the individual may stop using the system altogether as was the case in survey C-75. A unique improvement that was reported by a survey respondent was a child-proof tap. She recounted the numerous times her children would play with the tap and leave it on the open position, where the treated water would be wasted. A child proof tap could be added as a design element to resolve this issue.

Each and every survey respondent considered in the set of monitored households with filters described the proper cleaning method as per what was taught to them during the training session(s). These training sessions conducted during the distribution days should be continued in order to replicate the excellent retention of the proper cleaning method exhibited in Yipelgu. This success of the training sessions can potentially be attributed to the multiple opportunities the beneficiaries had to clarify or receive retraining regarding filter usage and maintenance as there was a community-wide demonstration followed by training in smaller groups of ten, and finally individual installation at each respective household.

The information conveyed during the training sessions did not exactly coincide with the abbreviated version of the training manual; corrections to these discrepancies have been provided in **Appendix E**. One such discrepancy entailed disassembling the tap fixture prior to regular cleaning, which was taught to the beneficiaries during the training sessions, but not included in the manual. Because reassembling the tap to the safe storage unit was reported as a difficulty, it was determined that the best resolution moving forward is to keep the tap fixed while cleaning. After cleaning the safe storage unit, the tap should be placed in the open position and must be thoroughly rinsed with treated water before dispensing filtered water. A small bowl of filtered water or cooled, boiled water can be placed under the tap mechanism, while the individual wipes the exterior of the tap with a clean cloth dipped into the filtered or cooled, boiled water. The tap handle was observed to be dirty in the majority of the households. Emphasis should be put on the importance of washing hands before dispensing water from the filter, in addition to cleaning the exterior of the tap daily.

Another aspect that should be emphasized in training sessions and also reflected in the Training Manual concerns the fill frequency per day. A larger system was recommended as an improvement by 3.8% of households surveyed. Respondents that cited this improvement stated that if the system were larger it could provide more treated water. During the research period, it was found that a respondent filled the filter on average of 1.7 times (n = 85). If the user filled the filtering element more often, more treated water could be available. As the volumetric capacity of the filter is fixed at 10 liters, it should be highly encouraged to increase fill frequency each day in order to treat more water. It must be also noted that if the filter is filled twice a day (morning and evening), the filter can easily treat 20 liters of drinking water per day.

6.1.1. Compliance and Correct Use Checklist

Many aspects and variables contributed to the average compliance with the Correct Use checklist. Average compliance is the percentage of total respondents that exhibited and/or reported the appropriate behavior itemized in the Correct Use checklist. Particular trends explained why a certain percent of respondents complied with the item in question. The items that had the lowest percentage of compliance were:

- placing the filter system on the prescribed stable base (34%) ;
- maintaining cleanliness of filtering element, safe storage unit, and tap (61%);
- keeping the filter system out of reach of possible contaminant sources (69%).

To address the issue of the noncompliance to a prescribed stable base, two main reasons influenced the overall Correct Use compliance rates. The majority of the households that initially set up the filter on a cemented mound, have moved them to makeshift unstable bases such as pots, tin cans, and piles of wood/rocks. One of the reasons for non-compliance involved relocating the filter due to the vulnerability of children knocking down the system as the mound typically is positioned next to the entrance of the household. The second reason entailed the conflict of purpose where the cemented mound traditionally is a special seat for honored guests. A possible solution is to only install filters with households that have cement blocks that the respondent would have to procure in order to make a contribution to the free or subsidized distribution of the HWTS technology. Future trainings need to insist on a dedicated permanent base in order for the beneficiary to receive the filter.

The visual cleanliness of the filtering element, safe storage unit, and tap yielded the second lowest compliance percent of 61.2%. Increasing the cleaning frequency and adopting the daily maintenance of the tap fixture can raise the compliance rate of this Correct Use checklist item.

The Correct Use item of placing the filter system "out of reach of possible contaminant sources" received the third lowest percent of compliant surveys. The possible contaminant sources considered were children, debris, and/or animals. In a few cases, children were observed to be tampering with the tap handle during the time of the survey. For some surveys the noted contaminant sources were articles of clothing, in particular sandals, and/or various cookware crowding the area surrounding in front of the filter system. If the filter system was placed on a low base, the risk of contamination of the tap spout would increase. Approximately 15% of households had animals (chickens and goats) near the proximity of the filter. Directing respondents to monitor children and animals around the filter, keep the area around the filter clear, and close the household entry/exit doors when no one occupies the dwelling can help prevent contaminant sources from interfering with the filter performance.

Other items of particular interest from the Correct Use checklist are as follows:

- System components rest evenly on each other;
- Turbid water undergoes settling for at least one hour before filtration; and finally,
- The drinking vessel is hygienic and located near filter.

Awareness of how to comply with these items can serve as a basis for improving future Correct Use and should be emphasized in revised instructions given during training.

The lid to the filtering system was the main contributor to noncompliance in regards to system components resting evenly on each other. A mix of "small" and "large" lids was found with the filter systems in the village of Yipelgu. "Small" lids did not cover the entirety of the pot leaving the lip exposed. "Large" lids on the other hand, fully covered the entirety of the pot including the rim and would rest evenly on the system. Since a "small" lid had to balance on the filtering element's rim, it was mostly the case that the lid would be tilted to one side. Although it was not observed that a "small" lid rendered the water in the top chamber uncovered; it could easily fall off, which could lead to debris entering and clogging the filtering element. The "small" lids were originally stockpiled for the ceramic cone-shaped filtering element, while the “larger” lids custom fit the ceramic hemispheric pot geometry. Future distributions should be of the large lids only.

It is also important to mention that stored water should settle overnight during the training session. The most common response to how long the respondent allows the stored water to settle before filling the ceramic pot is from morning when they fetch water to the afternoon when they fill the ceramic pot. However, settling time would be reduced if the respondent needs to fetch water in the morning and fill the filter upon their return to meet the needs of the day ahead.

Furthermore, the use of distinct filling and drinking vessels should be stressed in order to correctly use the filter. A number of respondents used the same vessel to fill the ceramic pot and also as their drinking water cup. Others are using two separate vessels for each action, but they are visually identical. This is problematic because contamination can easily occur in a mix-up of which vessel is designated for which specified purpose. In regards to the drinking vessel, the trainer should emphasize that the specified cup should remain atop the filter for ease of access.

6.1.2. Community Source Water Quality

The researcher visited 13 community water sources in the village of Yipelgu, most of which were surface water sources, the majority of which were earthen dams and are locally called “dugouts.” Reference to the community water sources’ total coliform, *E. coli*, and NTU values can be found in **Table 5-5**.

The Southeast Dam exhibited the lowest total coliform and *E. coli* concentrations of 6,700 and 310 MPN/100 mL, respectively. However, this water source did not possess the lowest NTU value. The lowest NTU value of 53 was sampled from the “Waterlilies” Dam, and the Lohu hand-dug well’s NTU value of 59 was a close second. However, the level of bacterial contamination in the “Waterlilies” Dam and the Lohu hand dugwell are not comparable to that of the Southeast Dam.

The microbiological water quality parameters of the Northeast Dam are approximately the same level to that of the Southeast Dam, but with a lower NTU value. **Therefore, it is recommended to fetch from the Northeast Dam as much as possible, which is about a 40 minute walk from the village center.** This recommendation can hold in the dry season, but verifying the cleanest water source in the rainy season must be determined. It is a great obstacle to purify unsafe water in rural settings because of cost, non-availability of chemicals, and responsibility required from a local operator. A more appropriate solution is to designate a water source that can yield pure water and protect it, rather than to try to treat polluted waters (Skinner, 2003). Although the Northeast Dam does not provide completely pure water, filtering the least polluted available water can increase the purity and acceptability of the ultimate drinking water.

Pre-treatment, defined in this thesis as sedimentation and bacteria die-off, of the water retrieved from the source before filling the filtering element plays an important role and contributes to the removal rates prior to filtration. As summarized in **Table 5-7**, pre-treatment alone showed an average total coliform LRV of 0.3, *E. coli* LRV of 0.5 and turbidity removal of 31.3%. Pre-treatment can assist and enhance the overall quality of the filtered drinking water. This emphasizes the importance of the respondents taking personal responsibilities to ensure optimal filter performance.

6.2. Overall Filter Performance Qualitative Discussion

Results show that the AfriClay filters distributed to the village of Yipelgu are generally improving the drinking water quality. This is evident in general trends, comparable results to similar studies, and protective/highly protective log reduction values.

Filter use rendered higher risk untreated water (stored sample) to lower risk treated water (filtered sample) as per WHO risk categories (**Table 5-9**) in terms of total coliform MPN, *E. coli* MPN, and NTU values. **Figures 5-4** to **5-6** depict this general trend.

E. coli and turbidity percent reductions of the AfriClay filters in this study are comparable to the plastic BioSand Filters in a similar study, which took place in Tamale, Ghana (Stauber et. al, 2012). **Table 6-1** compares the results of the two studies. The performance of the AfriClay filter generally equals or exceeds that of the BSF in terms of *E. coli* and NTU % reductions. Total coliform % reduction was not calculated in the plastic BioSand Filter (BSF) study. Although the two studies are of different HWTS technologies, both take place in the setting of the rural areas of Northern Ghana. Significantly, Stauber et. al (2012) found that at this level of performance, diarrheal disease reduction was 60%. While the Yiplegu monitoring and evaluation research did not measure diarrheal disease reduction, the comparable level of performance of the respective HWTS systems suggests that the AfriClay filter is also capable of reducing diarrheal disease to this level. Indeed the findings of Peletz (2006) and Johnson (2007) found a diarrheal reduction of 69% which is similar to that of Stauber et. al (2012).

Even though the AfriClay filter performed generally equal or better than the BSF (**Table 6-1)**, there was considerable variability in its performance based on total coliform and *E. coli* log reduction values. Consistency must be attained both in factory production and in Correct Use behavior. Summaries of the counts of filters which performed at specific total coliform and *E. coli* log reduction values can be found in **Table 6-2**.

Table 6-1: Comparison of % water quality parameter reductions across two studies.

% reductions	**AfriClay Filter (Cheng, 2013)**	**Plastic BioSand Filter* (Stauber, 2012)**
Total coliform	99	--
E. coli	98	97
NTU	80	67

* Plastic BSF percent reductions calculated from stored untreated water and direct filtrate.

Table 6-2: Number of AfriClay filters in LRV performance categories based on TC and *E. coli*.

Class	Counts based on TC LRV (n = 79)	Counts based on E. coli LRV (n = 76)
LRV < 0	5	4
0 ≤ LRV < 1	15	11
1 ≤ LRV < 2	23	30
2 ≤ LRV < 3	20	26
3 ≤ LRV < 4	9	4
LRV ≥ 4	7	1

As mentioned previously, the performance of the filter based on total coliform and *E. coli* LRVs show a similar trend, where some filters perform at the low and high ends and the majority achieved 1 to 2 LRV.

6.3. H_2S Bacteria MPN vs. Quanti-Tray®/2000 MPN Tests

The H_2S bacteria MPN and Quanti-Tray® MPN methods were investigated for possible correlations. Pure Home Water is transitioning to H_2S MPN bacterial testing from the IDEXX Quanti-Tray® MPN due to its accessibility, low-cost, and quantitative results. Relationships were investigated through establishing LRV thresholds, as well as significance tests for regression slope and correlation. Matched pairs t tests were also used to determine the presence or absence of statistically significant differences in the QT and H_2S LRVs. The LRV established thresholds did not yield any substantial relationship between the two methods. The significance tests for regression slope and correlation showed that there were no statistically significant linear relationship and correlations.

The matched pairs one-sample t tests could not gather enough significant evidence to reject the null hypothesis. Therefore, based on the observed data, there is no statistically significant difference between either QT total coliform and H_2S LRVs or QT *E. coli* and H_2S LRVs. A larger sample size will likely provide further conclusions and verify if there is a significant difference between the reported LRVs of the two methods (QT and H_2S MPN tests). However, it can be said that LRVs reported from H_2S tests exhibit a low bias and high variability if QT LRVs are considered the ideal value. A low bias meaning H_2S LRVs are not far from the ideal value, and high variability denoting scatter around the target value. In other words, both methods are relatively centered on the same LRV, which is a favorable result and supports the substitution of the H_2S MPN in place of the IDEXX Quanti-Tray®/2000 MPN test.

O'Keefe (2009) tested raw and improved water sources using H_2S P/A and QT. This thesis research tested stored water using H_2S MPN and QT. A comparison of these results is shown in **Table 6-3**. All the stored samples for this study are from unimproved water sources.

Table 6-3: MPN results for the stored water samples that were tested with both QT and H_2S tests.

Stored sample	QT TC (MPN/100 mL)	QT *E. coli* (MPN/100 mL)	H_2S Bacteria (MPN/ 100 mL)
A	691	1.0	832
B	9,060	30	190
C	5,172	79	390
D	4,352	78	648
E	5,650	100	567
F	5,540	100	143
G	1,203,300	200	224
H	20,640	520	648
I	10,540	1,100	648

As seen in **Table 6-3**, both tests (QT and H_2S) agree in all 9 stored samples that contamination is present (with an MPN result > 0), which corresponds to 0% Error calculated from a 2x2 contingency table as outlined by O'Keefe (2009). Error is defined as the sum of all false results by the H_2S test. O'Keefe (2009) found an Error of 6% for unimproved sources with a sample size of 85 water quality samples. The 0% Error calculated in this study is skewed since there were no samples that tested negative for contamination and only a small sample size (n = 9) was tested. A larger sample size is recommended to further validate the results found in the study by O'Keefe (2009) and to conduct more conclusive matched pairs one-sample t significance tests.

6.4. Correlation to Water Quality and Correct Use

The purpose of investigating Correct Use checklist items and survey variables in poor (< 1 LRV) and an equal number of well-performing filters based on either total coliform or *E. coli* LRV was to inform the variability in filter performance.

6.4.1. Two-method Approach: Compliance and Average LRV

Only one variable, "ceramic pot fill frequency per day", from the entire Correct Use survey achieved statistical significance based on total coliform LRV; however, other variables came close to statistical significance (approaching the critical chi-square or t test score as seen in **Tables 5-18** to **5-22**. In order not to disregard the variables that came close to statistical significance, it is useful to report the percentages that complied or exhibited the behavior measured by the variable. For example, since the Correct Use checklist item of settling stored water for more than an hour almost reached statistical significance with a calculated chi-square score of 1.56 (a score of 3.84 was needed to reach statistical significance), the percentages of those who did and did not comply will be reported based on their appropriate group (poor/well-performing based on total coliform or *E. coli* LRV). Reporting these percentages can provide a better sense of possible patterns that may achieve statistical significance if a larger sample size was tested.

Once the variable that almost attains statistical significance is identified and the compliant and non-compliant percentages are reported in poor and well-performing groups based on total coliform and/or *E. coli* LRVs, another method of investigation can be applied. This method considers the entire sample size (n = 85) and is referred to as the "Average LRV" method. The Average LRV investigation first requires the division of the entire sample size into two groups of either meeting or failing to demonstrate the survey variable. The average LRV is then reported for each group. The Average LRV method differs from what was initially used to examine the survey variables in the Results S**ection 5.5** since it concentrates on each variable first then reports LRV performance. What was done in **Section 5.5** was to first determine the filter performance, and then study survey variable compliance. The initial method will be referred to as the "Compliance" method. A summary of the different approaches is listed below.

- "Compliance" method – Approach employed in Results **Section 5.5**
  Purpose: Used to show if compliance affects LRV performance.
  Sample size: Considers only subset of entire sample size.
  Step 1: Examine poor (< 1 LRV) performing filters based on total coliform (n = 20) or *E. coli* (n =13) and an equal number of well performing filters in upper tier.
  Step 2: Calculate compliance rates for each survey variable within poor and well performing groups and test significance.
  Step 3 (Optional): If significance is not reached, report percent of respondents. that complied with variable in both poor and well performing groups.

- "Average LRV" method – Additional approach employed in Discussion **Section 6.4**
  Purpose: Used to show slight LRV improvements if respondent is compliant.
  Sample size: Considers entire sample size (n =85).
  Step 1: Divide entire sample size into compliant and non-compliant groups based on survey variable.
  Step 2: Calculate average log reduction value for compliant and non-compliant groups respectively and test significance.
  Step 3: If significance is not reached, report general trend of LRVs

6.4.2. Two-method Approach Applied to "Suspect" Variables

The variables that reported in this section might reach statistical significance if a larger sample size is tested, and can serve as the foundation of a future monitoring survey. Initially entering into this study, it was determined that in order to make the best use of time as many variables as possible should be tested. After completing the study there are now certain "suspect" variables (i.e. almost reaching statistical significance or highest significance score within its specific group) that can be proven to affect filter performance and should be part of a continued investigation. Although a larger sample size is necessary, survey variables that did not come close to statistically significance would unlikely reach this threshold even if a larger sample size had been used. Such variables can be disregarded in future surveys to save time and the researcher can test other variables not included in this study. A revised Correct Use survey that includes only the recommended variables is provided in **Appendix B**.

Table 6-4: Summary of compliance percents and average LRVs for Correct Use checklist variables that almost reach statistical significance.

		Compliance Method		Avg. LRV Method	
Survey Item	Water Quality Parameter	Compliance in poor LRV performing group (%)	Compliance in well LRV performing group (%)	Avg. LRV in non-compliant group	Avg. LRV in compliant group
Settling stored water for more than 1 hour	Total coliform	84 (N=20)	100 (N=20)	0.72 (N=6)	2.05 (N=73)
Tap nozzle is not being touched while dispensing	*E. coli*	90 (N=13)	92 (N=13)	1.12 (N=6)	1.85 (N=67)

As seen in **Table 6-4,** 20 filters considered in the poor performing group based on total coliform LRV were associated with 84% of the respondents reporting that they allow the source water to settle in a separate storage unit from the filtering system for at least one hour. The respondents linked to the 20 filters considered in the well-performing group based on TC LRV exhibited 100% compliance. Another method in examining this variable is to distinguish the respondents that were compliant and non-compliant from the entire sample size and then calculate the average LRV performance (i.e. Average LRV method).

Table 6-4 shows that the average total coliform LRV for the non-compliant group, where 6 surveys reported they allow less than one hour for settling, is 0.72 LRV. For the survey respondents that reported they allow the water to settle for at least one hour, their filters performed at an average total coliform LRV of 2.05. Those respondents who complied with this Correct Use checklist item achieved a higher TC LRV than those who did not comply (2.05 > 0.72 LRV). A two sample t significance test shows that the substantial difference exhibited in the distinct groups (compliant and non-compliant) reached statistical significance. Since statistical significance was reached, this suggests that allowing the stored water to settle for at least one hour will be associated with an increase of filter performance based on TC LRV. **Therefore, the duration of settling time is key, and contributes to a higher performing filter in terms of total coliform removal observed in this study.** Trainers must stress the importance of settling the water to be filtered for at least one hour to enhance the overall filter performance.

The same pattern can be stated for the Correct Use checklist item of avoiding contact with the tap nozzle while dispensing water from the AfriClay filter system as shown in **Table 6-4**. However, the difference between compliance percents based on performance level and the difference between average LRVs based on compliance are smaller than the variable of settling duration. Statistical significance in this case was not attained; nevertheless, users should be trained to prevent tap contamination and clean the tap mechanism regularly in order to increase bacterial log reduction values. A higher *E. coli* LRV of 1.85 was attained by filters associated with respondents who complied with this Correct Use checklist item.

Table 6-5: Summary of filter ownership duration for total coliform LRV groups

Compliance Method		Average LRV Method	
Avg. filter duration ownership in poor performing group	Avg. filter duration ownership in well-performing group	Avg. LRV in surveys that report owning filter for 1 month	Avg. LRV in surveys that report owning filter for 2 months
1.6 months (N=20)	1.3 months (N=20)	2.12 (N=43)	1.74 (N=36)

Table 6-5 shows that both methods (compliance and average LRV investigations) generally agree that if the respondent has the filter in her possession for a longer amount of time the performance of the filter based on total coliform LRV suffers. Statistical significance was not attained using either method. However, this exhibited pattern can be due to the loss of information taught during the training sessions retained as time passes or loss of interest in using/maintaining the system. In order to mitigate this issue, PHW could increase the level of community monitoring either via follow up visits or community water committee engagement. This can also serve as an opportunity to distribute replacement parts and instructional stickers, as it was observed that some of the stickers were peeling off.

Table: 6-6: Average LRV Investigation for month of filter production

Water Quality Parameter	March	April	May	June	July	Sept.	Oct.	Nov.
TC LRV (N=76)	1.52 (N=4)	2.39 (N=9)	1.79 (N=29)	1.39 (N=10)	2.14 (N=13)	1.83 (N=5)	2.68 (N=3)	3.19 (N=2)
E. coli LRV (N=75)	1.41 (N=4)	1.55 (N=9)	1.77 (N=27)	1.50 (N=10)	2.16 (N=14)	0.75 (N=5)	2.10 (N=4)	1.39 (N=2)

As seen in this study, some variables from the respondents' behavior may influence filter performance; however, further investigation regarding factory production variables is warranted as well. Since the Correct Use checklist score (unweighted and weighted) did not directly correlate to filter performance level, this might suggest that how the filter is produced holds more weight in the filter's performance than does the user's behavior. **Table 6-6** is inconclusive in terms of which month yielded the best performing filters in terms of total coliform and *E. coli* LRV's. There was no particular month associated with the highest LRV in both categories. This might relate to the fact that statistical significance using the Compliance method was not reached. A larger sample size is needed to determine if the month of production contributes to filter performance level. Once the month is determined, additional investigation can be conducted to examine the occurrences and/or changes in filter production within that time frame.

6.4.3. Two-method Approach for Fill and Cleaning Frequency

Since "ceramic pot fill frequency per day" was the only variable in the Correct Use checklist to achieve statistical significance with the Compliance method documented in **Section 5.5**, further examination of this variable is warranted.

Table 6-7: Summary of ceramic pot fill frequency per day

	Compliance Method		Average LRV Method	
Water Quality Parameter	Avg. # of fills/day in poor LRV performing group	Avg. # of fills/day in well LRV performing group	Avg. LRV in surveys that report ≤ 2 fills/day	Avg. LRV in surveys that report > 2 fills/day
Total coliform	1.88 (N=20)	1.45 (N=20)	1.99 (N=71)	1.55 (N=8)
E. coli	1.92 (N=13)	1.54 (N=13)	1.79 (N=69)	1.24 (N=7)

The two methods (Compliance and Average LRV methods) were again applied to the variable of ceramic pot fill frequency per day for total coliform and *E. coli* LRV, respectively. **Table 6-7** shows a relative trend (statistical significance was not achieved using the Average LRV method) of declining filter performance with filling the filtering element more frequently throughout the day. Since it is promoted to fill the system regularly during the day to meet the needs of the household, further examination should be conducted to verify if this instruction is inconsequential or detrimental to the filter's performance. The author suspects that combining filling and cleaning frequency may inform this issue further. First, cleaning frequency is examined as shown in **Table 6-8**.

Table 6-8: Summary of filter cleaning frequency.

	Compliance Method		Average LRV Method	
Water Quality Parameter	Avg. cleaning frequency in poor LRV performing group	Avg. cleaning frequency in well LRV performing group	Avg. LRV in surveys that report Cleaning every ≤ 3 days	Avg. LRV in surveys that report Cleaning every > 3 days
Total coliform	2.80 days (N=20)	2.95 days (N=20)	1.97 (N=68)	1.81 (N=11)
E. coli	3.31 days (N=13)	2.46 days (N=13)	1.76 (N=65)	1.63 (N=11)

Table 6-8 depicts survey respondents associated with well-performing filters based on *E. coli* LRVs cleaned the system more often (Compliance method). The results for the total coliform LRV do not necessarily follow the same trend as the *E. coli* LRV, which could be due to the inherent nature of total coliform (see S**ection 6.5** for further discussion) or the fact that filter cleaning frequency did not come as close to statistical significance using the Compliance method as the *E. coli* LRV groups did. The calculated t-scores using the Compliance method can be found in **Table 5-22**. If the Average LRV investigation is used, higher TC and *E. coli* LRVs are exhibited for filters that were associated with respondents who reported cleaning the system every 3 days or less.

Fill and cleaning frequency variables were noted separately during each survey. Combining the variables to create a new variable of "number of fills per cleaning" can be calculated with the information already collected. The two-method approach can be used. The two-sample t test was employed in order to test its significance in regards to well or poor-performance based on total coliform and *E. coli* log reduction values (Compliance method). A summary of the results can be found in **Table 6-9**.

Table 6-9: Summary of t-test results for "number of fills per cleaning" between filters that performed well and performed poorly based on total coliform log reduction values.

Category	Avg. # fills per cleaning	Calculated t-score	Critical t-score	Statistically Significant
TC LRV Well	**4.4**	0.832	>1.729	No
TC LRV Poor	5.5			
E. coli LRV Well	**3.8**	1.459	>1.782	No
E. coli LRV Poor	6.5			

Note: the critical t-score corresponds a significance level of p = 0.05.

Although the "number of fills per cleaning" did not reach statistical significance using the compliance method (**Table 6-9**), it still can be said that on average, filters that performed well based on total coliform and *E. coli* log reduction values reported a lower number of fills per cleaning than those in the poor performing categories.

Table 6-10: Average LRV investigation for "number of fills per cleaning."

Water Quality Parameter	Avg. LRV in surveys that report ≤ 4 fills/cleaning	Avg. LRV in surveys that report > 4 fills/cleaning
TC LRV	2.08 (N=44)	1.78 (N=35)
E. coli LRV	1.84 (N=42)	1.67 (N=34)

Table 6-10 summarizes the Average LRV method for "number of fills per cleaning." Although statistical significance was not reached when the two-sample t tests were conducted, it still can be said that TC and *E. coli* LRV increases as the "number of fills per cleaning" decreases from the observed data. In general, it would be in the best interest of the user to clean the filter for ≤ 4 fillings. If a beneficiary fills the filter in the morning and evening, which is recommended as per training session and manual, then it can be recommended to clean the filter after every 4 fillings or every 2 days. To avoid complex instruction, it is recommended that the trainer to teach the user to clean the filter every 2 days. Even though cleaning every 3 day is still satisfactory (LRVs ≥ 1) as seen in **Table 6-8**, a filter on average can achieve a TC LRV classified in the protective performance target (LRV ≥ 2) if cleaned every 2 days. More data collection and research is recommended to further validate this claim.

It is further recommended that some filters from different batches be tested at the PHW factory and/or laboratory. The filters can be "overstressed." A future researcher can experiment and investigate the number of fills before the entire system is cleaned that would yield an unacceptable performance level, i.e. achieving < 1 LRV. It is suggested that the researcher start with 4 fills before the system is cleaned as the benchmark to validate the claim recommended above. It should be noted that "number of fills per cleaning" or "fills per cleaning" does not refer to the fills each day, rather the number of fills between the time the respondent cleans the filtering system.

6.5. IDEXX Quanti-Tray®/2000 MPN Test Detection

"E. coli is a subgroup of fecal coliforms but variation in testing techniques can lead to ratios greater than 1" (Droste, 1997). From the data collected and analyzed in this study, total coliform and *E. coli* LRVs for a given filter are not necessarily similar in value, which can be due to a number of reasons.

The IDEXX Quanti-Tray®/2000 MPN test is approved and certified by the United States Environmental Protection Agency (US EPA) to accurately measure *E. coli* in groundwater and surface waters. IDEXX Quanti-Tray®/2000 Total coliform MPN is approved as a reliable indicator in groundwater, but not for surface waters. Therefore the IDEXX Quanti-Tray® MPN test can yield more accurate results for *E. coli*, but not necessarily for total coliform. Furthermore, since total coliform occurs naturally in the environment, it is not always associated with fecal contamination and may be abundant in a given sample (Droste, 1997).

Moreover, the Colilert® reagent has a limit to its efficiency in inhibiting the growth of indicator bacteria (IDEXX Technical Support, Personal communication, March 3, 2013). Therefore, the Quanti-Tray®/2000 MPN test is more susceptible to yield false positives for total coliform. As mentioned previously, capturing MPN results for *E. coli* was not the author's main concern as *E. coli* is not always present in all water samples. For further monitoring and evaluation efforts, it is recommended for the future researcher to find a balance in capturing quantitative results for both total coliform and *E. coli*, in addition to corroborate those results in comparison to H_2S MPN test results.

Page intentionally left blank.

7. Conclusion

Table 7-1: Summary of recommendations and revisions.

Future Survey Recommendations
• Pre-test surveys to mitigate courtesy responses, address translation issues, and add/remove relevant survey variables. • Place more emphasis on (1) objective measure and/or (2) direct observations as opposed to self-reporting of filter use. • Longitudinal study should be conducted that addresses Correct, Consistent, and Continuous Use.
Training Manual Revisions
• Tap fixture should remain fixed while cleaning safe storage unit. • User should clean tap fixture daily. • Emphasize hand-washing at critical times • Clean the AfriClay system after every 4 fills or at most every 2 days (for households using highly turbid water such as those in Yipelgu).
Training Session Recommendations
• Maintain organization of training sessions as conducted in Yipelgu. This scheme provides multiple opportunities for beneficiaries to ask questions and clarify information. • Teach users to fill the filtering element as much as possible in order to meet the needs of the day. • Insist on a permanent base for the filter. • Direct users to monitor children around filter. • Keep area around filter clear of objects and debris. • Allow the stored water to settle overnight or at least for more than 1 hour. • Use a different, dedicated vessel for filling and another for drinking. • Drinking vessels should remain on top of the filter for accessibility and contaminant prevention.
Pure Home Water Logistic Recommendations
• Replacement parts need to be accessible to beneficiary; follow-up visits or stockpile in village (business model or subsidized basis). • Consider testing community water sources (prior to distribution) to determine the least polluted and recommend to the village to fetch from this source. Turbidity tubes can be used for this purpose. • Increase level of community monitoring either via follow-up visits or community water engagement. Funds can possibly come from community contributions.
Factory Production Variables
• Higher flow rate is a desirable trait in future iterations of hemispheric filter without sacrificing bacterial removal efficiency. • Consider implementing a child proof tap. • Lids should easily fit around the lip of the filtering element.
Future Research
• A larger sample size for H_2S MPN should be tested to verify O'Keefe (2009) study H_2S P/A results and to conduct more conclusive matched pairs one-sample t significance tests. • Perform a bench scale test at PHW office/laboratory to determine the critical number of fills per cleaning that yields an unacceptable performance level.

The recommendations and issues that were introduced in **Chapter 6** are consolidated and summarized in **Table 7-1**.

The main goal and 3 objectives of this thesis research have been achieved. Monitoring and evaluation of a representative number of filters (n = 85) distributed to the village of Yipelgu in Ghana has been carried out.

(1) Focus on water quality data as the primary filter performance indicator.

The water quality data from stored and filtered samples was transformed into log reduction values, which enabled the author to compare the AfriClay filter's performance to HWTS international guidelines. Total coliform and *E. coli* log reduction values have been the major focus of the statistical analysis and subsequently assisted in identifying Correct Use survey variables that may affect filter performance. The AfriClay filter performed at a geometrically averaged 99%, 98%, 80% reductions for total coliform, *E. coli*, and turbidity respectively.

(2) Identify behavioral factors from correct use surveys that affect filter performance.

Filter performance coupled with several statistical analysis methods identified variables that relate to filter performance, namely "fill frequency per day" and "allowing stored water to settle for at least 1 hour." The underlying issue from more frequent fills per day may be related to cleaning frequency. A general trend from the observed data showed that in order to achieve a better LRV, the filter should be cleaned after every 4 fills or every 2 days. Allowing the stored water to settle for more than one hour can enhance pre-treatment (sedimentation and bacteria die-off) and contribute to the overall water quality of the consumed drinking water.

(3) Create a baseline and compile recommendations for future distributions/monitoring efforts.

The filter performance documented in this thesis can serve as comparison to future monitoring and evaluation efforts. It would be expected that the filters should perform at least to these reported levels (99% TC, 98% *E. coli*, and 80% turbidity reductions) or higher in future mass distributions. Recommendations for future surveys, Training Manual and sessions, PHW logistics, factory production, and future research can be found in **Table 7-1**. Revised Correct Use and proposed surveys that measure Consistent and Continuous Use can be found in **Appendices A – D**. The updated, abbreviated training manual can also be found in **Appendix E**. If these recommendations are implemented and emphasized, the 3C's and safe water for all will be realized at a larger scale.

8. References

Abt Associates, Inc. (2012). *Distribution of ceramic water purifiers through direct sales and retail sales pilots in Cambodia* (Rep.).

American Public Health Association, American Water Works Association, & Water Environment Federation. (2012). *Standard methods for examination of water and wastewater* (22nd ed.). Washington, DC: American Public Health Associaiton.

Chuang, P., Trottier, S., & Murcott, S. (2011). Comparison and verification of four field-based microbiological tests: H2S test, Easygel, Coliert, Petrifilm. *Journal of Water, Sanitation, and Hygiene for Development*, *1*(1), 68-85.

Clasen, T., Schmidt, W., Rabie, T., Roberts, I., & Caincross, S. (2007). *Interventions to improve water quality for preventing diarrhoea: Systematic review and meta-analysis* (Tech.).

Clopeck, K. L. (2009). *Monitoring and evaluation of household water treatment and safe storage technologies: The sustained use of the KOSIM ceramic water filter in Northern Region Ghana* (Unpublished master's thesis). Massachusetts Institute of Technology. Retrieved from http://web.mit.edu/watsan/docs_theses_ghana.html

Collin, C. (2009). *Biosand filtration of high turbidity water: Modified filter design and safe filtrate storage* (Unpublished master's thesis). Massachusetts Institute of Technology. Retrieved May 7, 2013, from http://web.mit.edu/watsan/docs_theses_ghana.html

Droste, R. L. (1997). *Theory and practice of water and wastewater treatment*. New York: J. Wiley.

Encyclopedia Britannica. (2013). Ghana. *Encyclopedia Britannica Online*. Retrieved April 28, 2013, from http://www.britannica.com/EBchecked/topic/232376/Ghana

Enger, K. S., Nelson, K. L., Rose, J. B., & Eisenberg, J. S. (2012). The joint effects of efficacy and compliance: A study of household water treatment and effectiveness against childhood diarrhea. *Water Research*, 1181-1190. Retrieved from www.sciencedirect.com

Fewtrell, L., Kaufmann, R., Kay, D., Enaroia, W., Haller, L., & Colford, J., Jr. (2005). *Water, sanitation, and hygiene interventions to reduce diarrhea in less developed countries: A systematic review and meta-analysis* (Publication).

Gerba, C. P. (2009). *Indicator microorganisms* (Publication).

Ghana Stastistical Service, & Ghana Health Service. (2009). *Ghana demographic and health survey 2008* (Tech.).

HACH. (2008). *Portable Turbidimeter Model 2100P instrument and procedure manual* [Pamphlet]. Hach Company.

Hach Company. (1997). *Water analysis handbook* (p. 239). Loveland Company.

IDEXX. (2013). Quanti-Tray and Quanti-Tray/2000. *IDEXX Laboratories*. Retrieved from http://www.idexx.com/view/xhtml/en_us/water/products/quanti-tray.jsf?SSOTOKEN=0

IDEXX Technical Support. (2013, March 3). [Telephone interview].

Johnson, S. M. (2007). *Health and water quality monitoring of Pure Home Water's ceramic filter dissemination in the Northern Region of Ghana* (Unpublished master's thesis). Massachusetts Institute of Technology. Retrieved May 7, 2013, from http://web.mit.edu/watsan/docs_theses_ghana.html

Lantagne, D., & Clasen, T. (2011). *Assessing the implementation of selected household water treatment and safe storage (HWTS) methods in emergency settings* (Tech.).

Lu, C. (2012). *Monitoring and evaluation of ceramic water filter and hand-washing intervention in Northern Ghana* (Unpublished master's thesis). Massachusetts Institute of Technology. Retrieved from http://web.mit.edu/watsan/docs_theses_ghana.html

Maps of the World. (2013). *Political map of Ghana*. Retrieved May 03, 2013, from http://www.mapsofworld.com/ghana/ghana-political-map.html

Mato, R. (2002). *Groundwater pollution in urban Dar Es Salaam, Tanzania: Assessing vulnerability and protection priorities* (Unpublished doctoral dissertation). Eidenhoven Technical University.

McSweeney, C., New, M., & Lizcano, G. (2008). *UNDP climate change country profile: Ghana* (Rep.).

Moore, D. S., McCabe, G. P., & Craig, B. A. (2012). *Introduction to the practice of statistics* (7th ed.). New York: W.H. Freeman and Company.

O'Keefe, S. F. (2009). *A study of alternative microbial indicators for drinking water quality in Northern Ghana* (Unpublished master's thesis). Massachusetts Institute of Technology. Retrieved from http://web.mit.edu/watsan/docs_theses_ghana.html

Peletz, R. L. (2006). *Cross-sectional epidemiological study on water and sanitation practices in the Northern Region of Ghana* (Unpublished master's thesis). Massachusetts Institute of Technology. Retrieved May 7, 2013, from http://web.mit.edu/watsan/docs_theses_ghana.html

Preacher, K. J. (2010). Calculation for chi-square test: An interactive calculation tool for chi-square tests of goodness of fit and independence. *Interactive Chi-Square Tests*. Retrieved March 18, 2013, from http://www.quantpsy.org/chisq/chisq.htm

Schaefer, D., Werchota, R., & Dolle, K. (2007). *MDG monitoring for urban water supply and sanitation* (Publication).

Skinner, B. (2003). *Small-scale water supply: A review of technologies*. London: ITDG.

Stauber, C. E., Kominek, B., Liang, K. R., Osman, M. K., & Sobsey, M. D. (2012). Evaluation of the impact of the plastic BioSand Filter on health and drinking water quality in rural Tamale, Ghana. *International Journal of Environmental Research and Public Health*. Retrieved from www.mdpi.com/journal/ijerph

Stevenson, M. M. (2008). *Monitoring effective use of household water treatment and safe storage technologies in Ethiopia and Ghana* (Unpublished master's thesis). Massachusetts Institute of Technology. Retrieved from http://web.mit.edu/watsan/docs_theses_global.html

Tchbanoglous, G., & Schoeder, E. D. (1985). *Water quality characteristics: Modeling and modification*. Prentice Hall.

USAID. (2010). *Access and behavioral outcome indicators for water, sanitation, and hygiene* (Publication).

Van Halem, D. (2006). *Ceramic silver impregnated pot filters for household drinking water treatment in developing countries* (Unpublished master's thesis). Delft University of Technology.

VanCalcar, J. E. (2006). *Collection and representation of GIS data to aid household water treatment and safe storage technology implementation in the Northern Region of Ghana* (Unpublished master's thesis). Massachusetts Institute of Technology. Retrieved from http://web.mit.edu/watsan/docs_theses_ghana.html

Waddington, H., Snilstveit, B., White, H., & Fewtrell, L. (2009). *Water, sanitation and hygiene interventions to combat childhood diarrhoea in developing countries* (Publication).

WHO, & UNICEF. (2010). Definitions and methods. *JMP*. Retrieved from http://www.wssinfo.org/

WHO, & UNICEF. (2012). *A toolkit for monitoring and evaluating household water treatment and safe storage programmes* (Publication). WHO.

WHO. (2011a). *Evaluating household water treatment options: Health-based targets and microbiological performance specifications* (Publication).

WHO. (2011b). *Guidelines for drinking-water quality* (4th ed., Publication).

WHO. (2013). Global estimates of environmental burden of disease. *World Health Organization*. Retrieved February 18, 2013, from http://www.who.int/quantifying_ehimpacts/global/envrf2004/en/index.html

Yang, H., Wright, J. A., Bain, R., Pedley, S., Elliot, J., & Gundry, S. W. (n.d.). *Accuracy of the H2S test: A systematic review of the influence of bacterial density and sample volume*. Manuscript, University of Southampton.

Ziff, S. E. (2009). *Siphon filter assessment for Northern Ghana* (Unpublished master's thesis). Massachusetts Insitute of Technology. Retrieved from http://web.mit.edu/watsan/docs_theses_ghana.html

Page intentionally left blank.

Appendices

Appendix A: Correct Use Survey – Field Version

Page intentionally left blank.

Monitoring and Evaluation of Pure Home Water's Hemispheric Ceramic Filter

Correct Use Survey: Yipelgu, Ghana UNICEF Distribution 2012 - 2013

Student/Surveyor Introduction

Hello, my name is Kristine Cheng and I am a student from Massachusetts Institute of Technology in the United States. I am working with partner(s) _________________Name(s) at Pure Home Water in Tamale, Ghana to conduct a survey on how your household uses the hemispheric ceramic filter. This survey is not a test in any way. All information we collect will be kept confidential, which means that we will not share the information you convey with others. The data will be kept only as a collection of the responses given by all survey participants. I would like to talk to the person in the household responsible for filter use and maintenance for about 30 minutes. Participation is completely voluntary. You may decline to answer any or all of the questions, and you may end the questionnaire at any time. At the end of the survey, I would also like to collect water samples related to your filter use.

Do you understand? Will you be willing to participate?

Yes □ No □

If NO, thank you for your time and I will end my questions here.

If YES, do you have any questions about the survey or may we begin?

Date and Time:		Survey Number:	
Interviewee Name:		Age:	*(Observe)* Gender: M or F
Filter Number:			
GPS Coordinates:			
Notes:			

1. Are you in charge of dispensing water from the filter, as well as its maintenance?
   a. If YES, continue with survey.
   b. If NO, ask who has this responsibility and ask to interview this individual instead.

General/household Information

2. Would you please tell us your name and the name of your compound so it is possible to contact you again?
   Household:_________________ Compound:_________________

3. What is your household status and relation to head of compound? _________________

4. How many people drink water from the AfriClay ceramic pot filter (CPF) system?
   # of Adults:_________________ # of Children:_________________

5. What serves as your water source in the **dry** season? (Multiple answers may apply, note location)

□ Stream	□ River	□ Dam	□ Pond
□ Lake	□ Spring	□ Borehole	□ Hand dug well (protected)
□ Hand dug well (unprotected)	□ Pipe	□ Rain	□ Other:

Is water normally available from this source? □ Yes □ No

6. What serves as your water source in the **wet** season? (Multiple answers may apply, note location)

□ Stream	□ River	□ Dam	□ Pond
□ Lake	□ Spring	□ Borehole	□ Hand dug well (protected)
□ Hand dug well (unprotected)	□ Pipe	□ Rain	□ Other:

Is water normally available from this source? □ Yes □ No

7. May I see your AfriClay (CPF) system and take note of its identification number?
   Filter #: _________________ Ceramic pot shape: _________________
   Note: Households in Yiplegu may have the flower pot shaped ceramic filtering element from previous distribution; continue with survey in either case.

8. Are you using the filter?
   If YES, proceed to **Correct Use Checklist**
   If NO, proceed to applicable **Additional Questions**

AfriClay ceramic pot filter (CPF) system includes ceramic pot, plastic safe-storage unit, lid, & tap

Instructions: For each observation, fill in Yes, No, or NA for observations that do not apply. Add up the total # of Yes, divide by the total # of observations made, and multiply by 100 for % Correct Use.		
Monitoring Observations	**Correct Use Checklist** Note: If question number is bolded, designates a non-observational question	Y/N/NA
Assembly	1. All components are present (CPF system + brush + instructional sticker)	
	2. Ceramic pot installed in the plastic safe-storage unit	
	3. Ceramic pot's rim fully covers the top rim of the safe storage container	
	4. CPF system components rest evenly on each other	
	5. CPF system is on level surface	
	6. CPF system on prescribed stable base (concrete blocks or cemented mound)	
	7. Base is approximately 1 foot high	
	8. Tap extends beyond edge of base	
	9. Tap shows no signs of leaking; washers are in proper sequence (fix if improper)	
	10. CPF system located against a wall, not in middle of room	
	11. CPF system located out of direct sunlight	
Treatment	**12.** Turbid water undergoes settling for at least one hour before filtration*	
	13. Ceramic pot is partially full or at least damp	
	14. Ceramic pot is not overfilled. Water level remains below lip of pot	
	15. Storage unit is not filled above the bottom of the ceramic pot	
Demonstration	**16.** Request that the respondent to pour you a cup of drinking water:	
	a. Used cup or calabash to scoop water from large "settling" container to fill filter	
	b. Cup or calabash used to fill filter is hygienic	
	c. Cup or calabash used to access filtered water is hygienic and located near filter	
	d. Filtered water is served directly from tap	
	e. Nozzle of tap is not being touched while dispensing filtered water	
	f. Sample collected safely (not touching water with hands)	
Safe Storage	17. There is water in the safe-storage unit	
	18. Lid kept in place and is securely covered, except when being filled	
	19. Safe-storage unit is clean inside and out (free of visible scum or scaling)	
	20. Out of reach of possible contaminant sources (children, debris, animals etc.)	
Maintenance	21. Ceramic pot, storage unit, and tap are clean	
	22. Ceramic pot, storage unit, and tap show no visible leaks or cracks	
	23. Safe storage unit shows no signs of stress (indicated by plastic turning whitish)	
	24. Respondent never uses soap or disinfectant with the ceramic pot itself	
	25. Instructional sticker intact on filter	

***Settling in household storage vessels, separate from AfriClay ceramic pot filter (CPF) system**

Additional Questions:

1. How long have you had this filter? _________________

2. If you are not using the filter, why? (Do not read options, circle all that apply)
    a. Filter/storage container/tap broke
    b. Did not like using it
    c. Felt it was not necessary
    d. Felt it was not improving the water quality
    e. Time consuming
    f. No longer present in household
    g. Found a better or more trusted source of water

3. Is the filter easy to use? □ Yes □ No

4. What is difficult about the filter? _________________

5. Ceramic pot filter fill frequency per day
   □ Once □ Twice □ Thrice □ More:

6. Ceramic pot filter is cleaned when (Multiple answers possible):
   □ It stopped filtering □ Flow rate is low □ Pot is dirty □ Container is dirty □ Other:

7. How often do you clean or plan to clean the filter?
   □ Daily □ Weekly □ Monthly □ Never

8. Describe how you would clean the filter and safe storage container (Note brush and soap use)
   □ Correct cleaning □ Incorrect cleaning

9. Filter problems (Multiple answers possible):

□ Breakage	Since:	Where: (Pot lip/side, Container, Other)
Reason:		
□ Leakage	Since:	Where: (Filter tap, Container, Other)
Reason:		
□ Other	Since:	Where:
Reason:		

10. Replacement parts required (Multiple answers possible):

□ Filter pot	□ Container	□ Lid	□ Ring lid
□ Tap	□ Brush	□ Washer(s)	□ Other

Water Quality Monitoring	
Samples from each household	Record of collection
"Stored" unfiltered water	□
Filtered water directly from tap	□
Source water Note: not necessary to test source water for every household. Once the primary/secondary sources are apparent within the village – take ~2-5 samples of each source and test.	□

Thank you for your time. Your support is much appreciated and will greatly help our study.

- End Survey -

Appendix B: Correct Use Survey – Revised Version

Page intentionally left blank.

<u>Monitoring and Evaluation of Pure Home Water's Hemispheric Ceramic Filter</u>

Revised Correct Use Survey

Student/Surveyor Introduction

Hello, my name is _______________and I am a researcher working with partner(s) __________Name(s) at Pure Home Water in Tamale, Ghana to conduct a survey on your household's drinking water management practices. This survey is not a test in any way. All information we collect will be kept confidential, which means that we will not share the information you convey with others. The data will be kept only as a collection of the responses given by all survey participants. I would like to talk to the person in the household responsible for the household's drinking water supply for about 30 minutes. Participation is completely voluntary. You may decline to answer any or all of the questions, and you may end the questionnaire at any time. At the end of the survey, I would also like to collect water samples of your drinking water.

Do you understand? Will you be willing to participate?

Yes □ No □

If NO, thank you for your time and I will end my questions here.

If YES, do you have any questions about the survey or may we begin?

Date and Time:		Survey Number:	
Interviewee Name:		Age:	*(Observe)* Gender: M or F
Filter Number:			
GPS Coordinates:			
Notes:			

1. Are you in charge of supplying and/or drinking water for the household?
    a. If YES, continue with survey.
    b. If NO, ask who has this responsibility and ask to interview this individual instead.

General/household Information

2. We would like to return to you in about **1 month** (same season that researcher is conducting survey at present) to ask similar questions. You may choose not to participate then, but would you please tell us your name and the name of your compound so it is possible to contact you again?
    Household:_________________ Compound:_________________

3. What is your household status and relation to head of compound? _________________

4. How many people live in your household?
    Total #:_________________ # of Children (≤ 5 y.o.) :_________________

5. What is your primary water source in the **dry** season? (Note location:_______________)

□ Stream	□ River	□ Dam	□ Pond
□ Lake	□ Spring	□ Borehole	□ Hand dug well (protected)
□ Hand dug well (unprotected)	□ Pipe	□ Rain	□ Other:

Is water normally available from this source during the dry season? □ Yes □ No

If NO, what is your secondary water source in the dry season? _________ (Note location)

6. What is your primary water source in the **wet** season? (Note location:_______________)

□ Stream	□ River	□ Dam	□ Pond
□ Lake	□ Spring	□ Borehole	□ Hand dug well (protected)
□ Hand dug well (unprotected)	□ Pipe	□ Rain	□ Other:

Is water normally available from this source during the wet season? □ Yes □ No
If NO, what is your secondary water source in the wet season? _________ (Note location)

7. Can you show me where you store your drinking water?
Type of container:____________________ Location of container:_____________________
Securely covered: Yes or No Visually hygienic: Yes or No

8. Do you treat your water between the time you fetch the water and prior to consumption? (Do not read options, multiple answers may apply)
□ Boil □ Chlorine tablets/liquid □ Cloth filter
□ Alum □ AfriClay filter □ Other: ________________
If AfriClay filter is recorded, proceed to **AfriClay Filter Questions**.

9. Could you show me how you take water from the containers?

□ Draw with cup/scoop without handle	□ Spigot	□ Other:
□ Draw with cup/scoop with handle	□ Pour directly	____________________

10. Have you ever purchased or received an AfriClay filter? If not recorded in **Question 8**, why are you not using the filter? (Do not read options; circle all that apply). Proceed to **Question 22**.
    a. Filter/storage container/tap broke
    b. Did not like using it
    c. Felt it was not necessary
    d. Felt it was not improving the water quality
    e. Time consuming
    f. No longer present in household
    g. Found a better or more trusted source of water

AfriClay Filter Questions

11. Did you purchase or receive the AfriClay filter? Who sold or distributed it to you?
□ Purchased from _______________________ □ Received from _______________________

12. How long have you had this filter? ______________(days/weeks/months/years)

13. How many people drink water from the AfriClay filter?
Total # :_________________ # of Children (≤ 5 y.o.) :_________________
If not the same # of people in **Question 4**, why do some people not use the filter?

14. Ceramic pot filter fill frequency per day
□ Once □ Twice □ Thrice □ More:

15. What are your reasons for cleaning the AfriClay filter? (Multiple answers possible):
□ It stopped filtering □ Flow rate is low □ Pot is dirty □ Container is dirty □ Other:

16. How often do you clean or plan to clean the filter?
□ Daily □ Every ___ day(s) □ Weekly □ Never

17. Describe how you would clean the filter, safe storage unit, and tap (Note brush and soap use)
   □ Correct cleaning □ Incorrect cleaning
   If INCORRECT, note improper step:____

18. May I see your AfriClay filter? Record identification number.

Ceramic pot shape: _________________	Filter #: _______________

19. How long do you let your stored water settle before filling the ceramic pot? _______(hrs/days)

AfriClay ceramic pot filter (CPF) system includes ceramic pot, plastic safe-storage unit, lid, & tap

*Instructions***:** For each observation, fill in Yes, No, or NA for observations that do not apply. Add up the total # of Yes, divide by the total # of observations made, and multiply by 100 for % Correct Use.		
Monitoring Observations	**Correct Use Checklist**	Y/N/NA
Assembly	1. All components are present (CPF system + brush + instructional sticker)	
	2. CPF system on recommended stable base (i.e. concrete blocks)	
	3. CPF system is on level surface	
	4. Base is approximately 1 foot high	
	5. Tap extends beyond edge of base	
	6. Tap shows no signs of leaking; washers are in proper sequence (fix if improper)	
	7. Lid securely covers entirety of the ceramic pot's lip	
	8. Ceramic pot's rim fully covers the top rim of the safe storage container	
	9. Area around CPF system is clear (no cookware, shoes, etc. blocking access)	
	10. Ceramic pot is partially full or at least damp	
	11. There is water in the safe storage unit	
Demonstration	**12.** Request that the respondent to pour you a cup of drinking water:	
	a. Used distinct, dedicated vessels for filling and dispensing purposes	
	b. Distinct, dedicated vessels for filling and dispensing purposes are hygienic	
	c. Dedicated vessel used to access filtered water is located near filter	
	d. Washed hands prior to dispensing filtered water	
	e. Filtered water is served directly from tap	
	f. Nozzle of tap is not being touched while dispensing filtered water	
	g. Sample collected safely (not touching water with hands)	
Maintenance	13. Tap handle and nozzle are visually hygienic	
	14. Lid and safe storage unit are clean inside and out (free of visible scum/scaling)	
	15. Ceramic pot, storage unit, and tap show no visible leaks, cracks, or stress	
	16. Brush is visually hygienic	

20. Filter problems (Multiple answers possible):

□ Breakage	Since:	Where: (Pot lip/side, Container, Other)
Reason:		
□ Leakage	Since:	Where: (Filter tap, Container, Other)
Reason:		
□ Other	Since:	Where:
Reason:		

21. Replacement parts required (Multiple answers possible):

□ Filter pot	□ Container	□ Lid	□ Ring lid
□ Tap	□ Brush	□ Washer(s)	□ Other

22. What can be improved about the AfriClay filter that would make it easier or convenient to use?

□ Faster flow rate	□ Larger system	□ Child proof tap
□ Less maintenance	□ Fragility of filtering element	□ Other: __________________

Water Quality Monitoring	
Samples from each household	Record of collection
"Stored" unfiltered water	□
Unfiltered water in ceramic pot (Existing)	□
Filtered water directly from tap	□
Source water Note: not necessary to test source water for every household. Once the primary/secondary sources are apparent within the village – take ~2-5 samples of each source and test.	□

Thank you for your time. Your support is much appreciated and will greatly help our study.

- End of Survey -

Appendix C: Consistent Use Survey – Proposed Version

Page intentionally left blank.

Monitoring and Evaluation of Pure Home Water's Hemispheric Ceramic Filter

Proposed Consistent Use Survey: 1 Month Follow-Up

Student/Surveyor Introduction

Hello, my name is ____________and I am a researcher working with partner(s) ___________Name(s) at Pure Home Water in Tamale, Ghana to conduct a survey on your household's drinking water management practices. This survey is not a test in any way. All information we collect will be kept confidential, which means that we will not share the information you convey with others. The data will be kept only as a collection of the responses given by all survey participants. I would like to talk to the person in the household responsible for the household's drinking water supply for about 30 minutes. Participation is completely voluntary. You may decline to answer any or all of the questions, and you may end the questionnaire at any time. At the end of the survey, I would also like to collect water samples of your drinking water.

Do you understand? Will you be willing to participate?

Yes □ No □

If NO, thank you for your time and I will end my questions here.

If YES, do you have any questions about the survey or may we begin?

Date and Time:		Survey Number:	
Interviewee Name:		Age:	*(Observe)* Gender: M or F
Filter Number:			
GPS Coordinates:			
Notes:			

1. Are you in charge of supplying and/or treating drinking water for the household?
   a. If YES, continue with survey.
   b. If NO, ask who has this responsibility and ask to interview this individual instead.

General/household Information

2. We would like to return to you in about **6 months** (different season that researcher is conducting survey at present) to ask similar questions. You may choose not to participate then, but would you please tell us your name and the name of your compound so it is possible to contact you again?
   Household:________________ Compound:________________

3. What is your household status and relation to head of compound? ________________

4. How many people live in your household?
   Total #:________________ # of Children (≤ 5 y.o.) :________________

5. What is your primary water source in the **dry** season? (Note location:______________)

□ Stream	□ River	□ Dam	□ Pond
□ Lake	□ Spring	□ Borehole	□ Hand dug well (protected)
□ Hand dug well (unprotected)	□ Pipe	□ Rain	□ Other:

Is water normally available from this source during the dry season? □ Yes □ No

If NO, what is your secondary water source in the dry season? _________ (Note location)

6. What is your primary water source in the **wet** season? (Note location:_______________)

□ Stream	□ River	□ Dam	□ Pond
□ Lake	□ Spring	□ Borehole	□ Hand dug well (protected)
□ Hand dug well (unprotected)	□ Pipe	□ Rain	□ Other:

Is water normally available from this source during the wet season? □ Yes □ No
If NO, what is your secondary water source in the wet season? _________ (Note location)

7. Can you show me where you store your drinking water?
Type of container:____________________ Location of container:_____________________
Securely covered: Yes or No Visually hygienic: Yes or No

8. Do you treat your water between the time you fetch the water and prior to consumption? (Do not read options, multiple answers may apply)
□ Boil □ Chlorine tablets/liquid □ Cloth filter
□ Alum □ AfriClay filter □ Other: ________________
If AfriClay filter is recorded, proceed to **AfriClay Filter Questions**.

9. Could you show me how you take water from the containers?

□ Draw with cup/scoop without handle	□ Spigot	□ Other: ___________________
□ Draw with cup/scoop with handle	□ Pour directly	

10. Have you ever purchased or received an AfriClay filter? If not recorded in **Question 8**, why are you not using the filter? (Do not read options; circle all that apply). Proceed to **Question 25**.
    a. Filter/storage container/tap broke
    b. Did not like using it
    c. Felt it was not necessary
    d. Felt it was not improving the water quality
    e. Time consuming
    f. No longer present in household
    g. Found a better or more trusted source of water

AfriClay Filter Questions

11. Did you purchase or receive the AfriClay filter? Who sold or distributed it to you?
□ Purchased from ________________________ □ Received from ________________________

12. How long have you had this filter? _______________(days/weeks/months/years)

13. Have you ever used the AfriClay filter? □ Yes □ No
    a. In the last month? □ Yes □ No
    b. In the last week? □ Yes □ No
    c. Always? □ Yes □ No

14. When do you not use? (Multiple answers possible)
    a. When there is no money
    b. When there is no time
    c. During the rainy season
    d. During the dry season
    e. Never in use
    f. Other: _____________

15. How many people drink water from the AfriClay filter?
    Total # :_________________ # of Children (≤ 5 y.o.) :_________________
    If not the same # of people in **Question 4**, why do some people not use the filter?

16. How often do children in your household drink untreated water?
    □ Always □ Usually □ Sometimes □ Never

17. If not always, where do they drink untreated water?
    □ School □ Work □ Religious center □ Traveling □ In fields □ Other:___________

18. Ceramic pot filter fill frequency per day
    □ Once □ Twice □ Thrice □ More:

19. What are your reasons for cleaning the AfriClay filter? (Multiple answers possible):
    □ It stopped filtering □ Flow rate is low □ Pot is dirty □ Container is dirty □ Other:

20. How often do you clean or plan to clean the filter?
    □ Daily □ Every ___ day(s) □ Weekly □ Never

21. Describe how you would clean the filter, safe storage unit, and tap (Note brush and soap use)
    □ Correct cleaning □ Incorrect cleaning
    If INCORRECT, note improper step: ____

22. May I see your AfriClay filter? Record identification number.

Ceramic pot shape: _________________	Filter #: _______________

23. How long do you let your stored water settle before filling the ceramic pot? _______(hrs/days)

AfriClay ceramic pot filter (CPF) system includes ceramic pot, plastic safe-storage unit, lid, & tap

Instructions: For each observation, fill in Yes, No, or NA for observations that do not apply. Add up the total # of Yes, divide by the total # of observations made, and multiply by 100 for % Correct Use.		
Monitoring Observations	**Correct Use Checklist**	Y/N/NA
Assembly	1. All components are present (CPF system + brush + instructional sticker)	
	2. CPF system on recommended stable base (i.e. concrete blocks)	
	3. CPF system is on level surface	
	4. Base is approximately 1 foot high	
	5. Tap extends beyond edge of base	
	6. Tap shows no signs of leaking; washers are in proper sequence (fix if improper)	
	7. Lid securely covers entirety of the ceramic pot's lip	
	8. Ceramic pot's rim fully covers the top rim of the safe storage container	
	9. Area around CPF system is clear (no cookware, shoes, etc. blocking access)	
	10. Ceramic pot is partially full or at least damp	
	11. There is water in the safe storage unit	
Demonstration	**12.** Request that the respondent to pour you a cup of drinking water:	
	a. Used distinct, dedicated vessels for filling and dispensing purposes	
	b. Distinct, dedicated vessels for filling and dispensing purposes are hygienic	
	c. Dedicated vessel used to access filtered water is located near filter	
	d. Washed hands prior to dispensing filtered water	
	e. Filtered water is served directly from tap	
	f. Nozzle of tap is not being touched while dispensing filtered water	
	g. Sample collected safely (not touching water with hands)	
Maintenance	13. Tap handle and nozzle are visually hygienic	
	14. Lid and safe storage unit are clean inside and out (free of visible scum/scaling)	
	15. Ceramic pot, storage unit, and tap show no visible leaks, cracks, or stress	
	16. Brush is visually hygienic	

23. Filter problems (Multiple answers possible):

□ Breakage	Since:	Where: (Pot lip/side, Container, Other)
Reason:		
□ Leakage	Since:	Where: (Filter tap, Container, Other)
Reason:		
□ Other	Since:	Where:
Reason:		

24. Replacement parts required (Multiple answers possible):

□ Filter pot	□ Container	□ Lid	□ Ring lid
□ Tap	□ Brush	□ Washer(s)	□ Other

25. What can be improved about the AfriClay filter that would make it easier or convenient to use?

□ Faster flow rate	□ Larger system	□ Child proof tap
□ Less maintenance	□ Fragility of filtering element	□ Other: _________________

Water Quality Monitoring	
Samples from each household	Record of collection
"Stored" unfiltered water	□
Unfiltered water in ceramic pot (Existing)	□
Filtered water directly from tap	□
Source water Note: not necessary to test source water for every household. Once the primary/secondary sources are apparent within the village – take ~2-5 samples of each source and test.	□

Thank you for your time. Your support is much appreciated and will greatly help our study.

- End of Survey -

Page intentionally left blank.

Appendix D: Continuous Use Survey – Proposed Version

Page intentionally left blank.

Monitoring and Evaluation of Pure Home Water's Hemispheric Ceramic Filter

Proposed Continuous Use Survey: 6 Month Follow-Up

Student/Surveyor Introduction

Hello, my name is ______________and I am a researcher working with partner(s) _____________Name(s) at Pure Home Water in Tamale, Ghana to conduct a survey on your household's drinking water management practices. This survey is not a test in any way. All information we collect will be kept confidential, which means that we will not share the information you convey with others. The data will be kept only as a collection of the responses given by all survey participants. I would like to talk to the person in the household responsible for the household's drinking water supply for about 30 minutes. Participation is completely voluntary. You may decline to answer any or all of the questions, and you may end the questionnaire at any time. At the end of the survey, I would also like to collect water samples of your drinking water.

Do you understand? Will you be willing to participate?

Yes □ No □

If NO, thank you for your time and I will end my questions here.

If YES, do you have any questions about the survey or may we begin?

Date and Time:			Survey Number:
Interviewee Name:		Age:	*(Observe)* Gender: M or F
Filter Number:			
GPS Coordinates:			
Notes:			

1. Are you in charge of supplying and/or drinking water for the household?
    a. If YES, continue with survey.
    b. If NO, ask who has this responsibility and ask to interview this individual instead.

General/household Information

2. We would like to return to you in about **1 year** to ask the same questions. You may choose not to participate then, but would you please tell us your name and the name of your compound so it is possible to contact you again?
   Household:__________________ Compound:__________________

3. What is your household status and relation to head of compound? __________________

4. How many people live in your household?
   Total #:__________________ # of Children (≤ 5 y.o.) :__________________

5. What is your primary water source in the **dry** season? (Note location:________________)

□ Stream	□ River	□ Dam	□ Pond
□ Lake	□ Spring	□ Borehole	□ Hand dug well (protected)
□ Hand dug well (unprotected)	□ Pipe	□ Rain	□ Other:

   Is water normally available from this source during the dry season? □ Yes □ No
   If NO, what is your secondary water source in the dry season? _________ (Note location)

6. What is your primary water source in the **wet** season? (Note location:______________)

□ Stream	□ River	□ Dam	□ Pond
□ Lake	□ Spring	□ Borehole	□ Hand dug well (protected)
□ Hand dug well (unprotected)	□ Pipe	□ Rain	□ Other:

Is water normally available from this source during the wet season? □ Yes □ No
If NO, what is your secondary water source in the wet season? _________ (Note location)

7. Can you show me where you store your drinking water?
Type of container:___________________ Location of container:____________________
Securely covered: Yes or No Visually hygienic: Yes or No

8. Do you apply any treatment between the time you fetch the water and prior to consumption? (Do not read options, multiple answers may apply)
□ Boil □ Chlorine tablets/liquid □ Cloth filter
□ Alum □ AfriClay Filter □ Other: ________________
If AfriClay filter is recorded, proceed to **AfriClay Filter Questions**.

9. Could you show me how you take water from the containers?

□ Draw with cup/scoop without handle	□ Spigot	□ Other:
□ Draw with cup/scoop with handle	□ Pour directly	__________________

10. Have you ever purchased or received a AfriClay filter? If not recorded in **Question 8**, why are you not using the filter? (Do not read options; circle all that apply). Proceed to **Question 25**.
    a. Filter/storage container/tap broke
    b. Did not like using it
    c. Felt it was not necessary
    d. Felt it was not improving the water quality
    e. Time consuming
    f. No longer present in household
    g. Found a better or more trusted source of water

AfriClay Filter Questions

11. Did you purchase or receive the AfriClay filter? Who sold or distributed it to you?
□ Purchased from ______________________ □ Received from ______________________

12. How long have you had this filter? ______________(days/weeks/months/years)

13. Have you ever used the AfriClay filter? □ Yes □ No
    a. In the last month? □ Yes □ No
    b. In the last week? □ Yes □ No
    c. Always? □ Yes □ No

14. When do you not use? (Multiple answers possible)
    a. When there is no money
    b. When there is no time
    c. During the rainy season
    d. During the dry season
    e. Never in use
    f. Other: _____________

15. How many people drink water from the AfriClay filter?
    Total # :_________________ # of Children (≤ 5 y.o.) :_________________
    If not the same # of people in **Question 4**, why do some people not use the CPF system?

16. How often do children in your household drink untreated water?
    □ Always □ Usually □ Sometimes □ Never

17. If not always, where do they drink untreated water?
    □ School □ Work □ Religious center □ Traveling □ In fields □ Other:___________

18. Ceramic pot filter fill frequency per day
    □ Once □ Twice □ Thrice □ More:

19. What are your reasons for cleaning the AfriClay filter? (Multiple answers possible):
    □ It stopped filtering □ Flow rate is low □ Pot is dirty □ Container is dirty □ Other:

20. How often do you clean or plan to clean the filter?
    □ Daily □ Every ___ day(s) □ Weekly □ Never

21. Describe how you would clean the filter, safe storage unit, and tap (Note brush and soap use)
    □ Correct cleaning □ Incorrect cleaning
    If INCORRECT, note improper step: ____

22. May I see your AfriClay filter? Record identification number.

Ceramic pot shape: _________________	Filter #: _______________

AfriClay ceramic pot filter (CPF) system includes ceramic pot, plastic safe-storage unit, lid, & tap

Instructions: For each observation, fill in Yes, No, or NA for observations that do not apply. Add up the total # of Yes, divide by the total # of observations made, and multiply by 100 for % Correct Use.		
Monitoring Observations	**Correct Use Checklist**	Yes/No/ or NA
Assembly	1. All components are present (CPF system + brush + instructional sticker)	
	2. CPF system on recommended stable base (i.e. concrete blocks)	
	3. CPF system is on level surface	
	4. Base is approximately 1 foot high	
	5. Tap extends beyond edge of base	
	6. Tap shows no signs of leaking; washers are in proper sequence (fix if improper)	
	7. Lid securely covers entirety of the ceramic pot's lip	
	8. Ceramic pot's rim fully covers the top rim of the safe storage container	
	9. Area around CPF system is clear (no cookware, shoes, etc. blocking access)	
	10. Ceramic pot is partially full or at least damp	
	11. There is water in the safe storage unit	
Demonstration	**12.** Request that the respondent to pour you a cup of drinking water:	
	a. Used distinct, dedicated vessels for filling and dispensing purposes	
	b. Distinct, dedicated vessels for filling and dispensing purposes are hygienic	
	c. Dedicated vessel used to access filtered water is located near filter	
	d. Washed hands prior to dispensing filtered water	
	e. Filtered water is served directly from tap	
	f. Nozzle of tap is not being touched while dispensing filtered water	
	g. Sample collected safely (not touching water with hands)	
Maintenance	13. Tap handle and nozzle are visually hygienic	
	14. Lid and safe storage unit are clean inside and out (free of visible scum/scaling)	
	15. Ceramic pot, storage unit, and tap show no visible leaks, cracks, or stress	
	16. Brush is visually hygienic	

23. Filter problems (Multiple answers possible):

□ Breakage	Since:	Where: (Pot lip/side, Container, Other)
Reason:		
□ Leakage	Since:	Where: (Filter tap, Container, Other)
Reason:		
□ Other	Since:	Where:
Reason:		

24. Replacement parts required (Multiple answers possible):

□ Filter pot	□ Container	□ Lid	□ Ring lid
□ Tap	□ Brush	□ Washer(s)	□ Other

25. What can be improved about the AfriClay filter that would make it easier or convenient to use?

□ Faster flow rate	□ Larger system	□ Child proof tap
□ Less maintenance	□ Fragility of filtering element	□ Other: _________________

Water Quality Monitoring	
Samples from each household	Record of collection
"Stored" unfiltered water	□
Unfiltered water in ceramic pot (Existing)	□
Filtered water directly from tap	□
Source water Note: not necessary to test source water for every household. Once the primary/secondary sources are apparent within the village – take ~2-5 samples of each source and test.	□

Thank you for your time. Your support is much appreciated and will greatly help our study.

- End of Survey -

Page intentionally left blank.

Appendix E: Revised Abbreviated AfriClay Training Manual

Page intentionally left blank.

PURE HOME WATER

TRAINING MANUAL

The AfriClay Filter

The AfriClay filter is a ceramic pot filter invented by Fernando Mazariegos in Guatemala in 1981 and subsequently adopted and globally promoted by Ron Rivera and Manny Hernandez of the non-governmental organization *Potters for Peace* as well as by various independent groups and ceramic manufacturers. The AfriClay version produced by Pure Home Water (PHW) in Tamale, Ghana consists of a ceramic pot, plastic safe-storage container, lid, tap, brush, instructional sticker and one AquaTab®.

3 C's: Correct, Consistent and Continuous Use

The AfriClay filter contributes to a happy and healthy family. The benefits of the filter can only, however, be obtained by the 3 C's: Correct, Consistent, and Continuous Use.

Correct Use: Following the instructions given in training sessions and depicted on the instructional sticker.

Consistent Use: Using the filter every day.

Continuous Use: Using the filter throughout the year, both during the dry season as well as during the wet season.

Assembling and Cleaning the AfriClay Filter Before First Use

Bring a large pot of water to a rolling boil and let cool to room temperature. Wash your hands thoroughly with soap. Pour some of the boiled, cooled water into the overturned lid of the filter and wash the lid. Place ceramic pot upside down on the overturned lid and set aside.

Pour some of the boiled, cooled water into a clean basin. Add the AquaTab® to the boiled, cooled water (about 4-6 liters is sufficient). Once the tablet has dissolved, use this water and recommended soap to wash the safe storage container. Place the clean storage container on the stable base. KEY or Banku soap is suggested to wash and rinse the plastic parts thoroughly. Do not use perfumed soap, dish soap or laundry detergent, as this will affect the water taste.

Use the AquaTab® water in the basin to wash the parts of the tap with soap. Rinse thoroughly with boiled, cooled water to wash off all soap residue.

Install the tap as instructed on the next page.

Invert the ceramic pot on the overturned lid and pour into the ceramic pot a small amount of boiled, cooled water that has NOT been treated with AquaTab®. Use the brush to scrub the inside and outside of the ceramic pot. <u>Never use soap on the ceramic pot</u>! <u>Never use AquaTab® water on the ceramic pot!</u>

Carefully place the ceramic pot in the top of the safe storage container. Do not hold the ceramic pot on the sides or bottom, rather grasp by the rim of the pot.

Use remaining AquaTab® water to rinse the lid. Place lid over the cleaned filter. Remind the user that the Aquatab® is only necessary for the first cleaning. The Aquatab® is not required for regular filter maintenance.

Tap Installation

Wash your hands thoroughly with soap.

Place one washer on the neck of the tap making sure that the flat side is facing the tap handle.

Insert the neck of the tap through the hole at the base of the safe storage container.

Place the second washer on the neck of the tap, the flat side facing away from the safe storage container.

Tighten the nut onto the second washer; making sure that its flat side faces the washer.

The area around the tap is the most likely place for the safe storage container to break. Never put pressure on the tap (i.e. lean the filter onto the side where the tap attaches). Never tip the safe storage container to remove water.

An **incorrectly installed tap** will leak causing many users to believe that the tap itself is broken. A simple reinstallation of the tap can solve many leakage problems.

Check to make sure that the washers are correctly oriented; the flat side facing away from the bucket (see depiction for step 4 on the previous page for guidance).

Make sure that the tap is tightened securely. Do NOT tighten extremely.

Check the tap handle for a loose seal (i.e. always in the open position).

Creating a Stable Base

Locate a stable base that is approximately 1 foot high and large enough to easily accommodate the filter. Four cement bricks provide an excellent base, or you can use a stable stool or small table. Place that base on level ground in a safe location inside the home, away from potential tripping hazards like children or livestock. The base should not be near the entrance or exit of household. Place the safe storage container on the base so that the tap extends beyond the edge of the base. Trainers must insist on a permanent, stable base. Keep area around the filter clear of cookware, shoes, etc.

"You have to be very gentle with the pot because you love it."

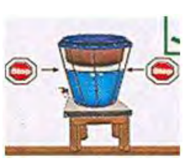
Mr. Daniel Appiah - PHW staff member.

Filter Use

Fetch water.

Fill the ceramic pot with the cleanest possible source of water available. In all cases, draw from water that has been allowed to settle overnight or at least for 1 hour in a separate storage vessel. It is very important for the water to settle.

Use a basin, cup, or calabash to scoop water from larger storage vessels, as this will reduce the chance of the filter being knocked over. The vessel used to fill the ceramic pot should be completely different from the dedicated drinking water cup. User is encouraged to fill the ceramic pot as many times throughout the day to meet the household drinking water needs.



Do not filter water beyond the indicated STOP line on the instructional sticker. After filling, always place the clean lid on the filter.

Carefully wash a cup with boiled, cooled soapy water. Wash hands before dispensing the filtered water into this clean cup using the tap.

Always keep this dedicated, clean cup on top of the filter! Never use this dedicated, clean cup to fill the ceramic pot.

Regular Filter Maintenance

The AfriClay filter should be **cleaned every 4 fills or at most every 2 days** to remove debris that accumulates on the inside of the ceramic pot. Between cleanings, the tap handle should be wiped down with a clean cloth soaked in filtered or cooled, boiled water whenever possible.

- ✓ Bring a large pot of water to a rolling boil and let cool to room temperature. Filtered water can be used in place of boiled, cooled water.
- ✓ Wash your hands thoroughly with soap.
- ✓ Pour some of the boiled, cooled water or filtered water into the overturned lid of the filter. Rinse lid with this water.
- ✓ Place the ceramic pot on the overturned lid and pour a small amount of the boiled, cooled or filtered water into the ceramic pot.
- ✓ Use the brush to scrub the inside and outside of the ceramic pot, without using soap.
- ✓ Using the remaining filtered or boiled, cooled water, add soap and wash the other plastic parts (including the tap). The tap should remain installed while cleaning the safe storage unit.
- ✓ Rinse off the soap with boiled, cooled water. Remember to place tap in the “open” position so that the soap can be rinsed out thoroughly.

Contamination

It is very easy to contaminate the AfriClay filter while cleaning. For this reason it is important to stress several aspects of proper use and cleaning.

<u>Filtering Water</u>

- ✓ Do not filter water past the lowest level of the ceramic pot (i.e. do not filter water beyond the indicated STOP line).
- ✓ Do not overfill the ceramic pot, as dirty water may seep over the top and into the safe storage container.
- ✓ Dedicate a specific cup for drinking and keep it clean and on top of the filter at all times.
- ✓ Never use the same cup to fill the ceramic pot. The vessel used to fill the ceramic pot should be completely different from the cup used for drinking.

<u>Cleaning</u>

- ✓ Always instruct users to make sure to allow the ceramic pot to completely drain or empty the water before removing the ceramic pot for washing.
- ✓ Always use filtered or boiled, cooled water to clean the AfriClay filter. NEVER USE UNTREATED WATER FOR CLEANING.
- ✓ Use soap to clean the inside of the safe storage container.
- ✓ DO NOT USE SOAP to clean the ceramic pot.

<u>Handling</u>

- ✓ Do not touch the outer part of the filter while cleaning. Make sure to hold it only at the rim. Touching the outer part will cause contamination.
- ✓ Do not place the ceramic pot on the ground, floor, on your leg or on any other unclean surface during cleaning. Instead, clean the lid, place it upside down on a stable base and place the ceramic pot on top of it.
- ✓ Always wash your hands with soap before reaching into the safe storage container to affix the tap.

<u>Tap</u>

- ✓ Never touch the nozzle of the tap or let it touch the ground or floor of the house. Do not let young children with dirty hands or animals near the tap. This can cause contamination of the clean water passing through the tap.
- ✓ Do not set the safe storage container on the ground while cleaning. This may contaminate the outflow nozzle of the tap.
- ✓ Wash hands before dispensing water from the filter in order to maintain cleanliness of tap.
- ✓ Wipe down tap handle with a clean cloth soaked in filtered or boiled, cooled water as much as possible between cleaning the entire filter system.

Quality Control

It is important to identify damaged components early. The ceramic pot is extremely fragile and should be handled with care. Before it is distributed to retailers or users, each pot should be checked for visible breaks and chips, and to make sure it has a bell-like, rather than “clunky”, sound. Symptoms of a broken ceramic pot are:

- ❑ A pot whose rim does not fully cover the top rim of the safe storage container (i.e. visible gaps between the top rim and the ceramic pot).
- ❑ A visible crack or chip.
- ❑ A lip that is not smooth or level at the bottom or is not at a right angle to the pot all around.
- ❑ When lightly struck, the ceramic pot should sound like a bell. If the sound is clunky, there is a hairline crack in the pot.

Visible Chips or Cracks

In addition, safe storage containers can also be damaged. Visually inspect all safe storage containers and lids for:

- ✓ Cracks;
- ✓ Stress (indicated by plastic turning a whitish color);
- ✓ Defective tap holes (diameter too large or too small for the tap to fit, many burrs or a poorly cut, jagged hole).

Discard and replace all defective ceramic pots or damaged safe storage containers.

Quality Control Checklists

AfriClay Filter Components

- ✓ Ceramic pot;
- ✓ Safe storage container;
- ✓ Lid;
- ✓ Brush;
- ✓ Instructional sticker affixed to container directly above the tap
- ✓ Tap;
- ✓ One AquaTab®.

Receiving Filters

- ✓ Inspect ceramic pots and other components for breakage.
- ✓ Record and report all broken items to the PHW Project Manager.
- ✓ Affix the instructional sticker to the outside of the safe storage container. Place it centered above the tap with the STOP LINE one inch below the level of the bottom of the ceramic pot, which you should be able to see through the safe storage container.
- ✓ Place all filters that have passed inspection into the PHW stockroom.

Pre-Loading Stage Checklist

- ✓ Set aside the required number of filters, lids, taps, brushes, AquaTabs®, plus several extra to account for potential breakage during delivery.
- ✓ Inspect all the ceramic pots for breakage.
- ✓ Discard all defective ceramic pots and replace with good ceramic pots.
- ✓ Visually inspect all safe storage containers, and lids for stress and breakage.
- ✓ Return all defective safe storage containers to PHW Project Manager.
- ✓ Pack the filters into the truck making sure to cover them with a waterproof tarp and tie them down carefully. Start packing from the front of the bed to the back.

Delivery Checklist

- ✓ Check filters for breakage. If you find one that can be used to demonstrate the hairline crack “clunky” sound, set it aside for the training session.
- ✓ Check safe storage containers for breakage or stress.
- ✓ Record any component breakage and replace.

Appendix F: Chi-square Distribution Critical Values

Page intentionally left blank.

Table entry for p is the critical value $(\chi^2)^*$ with probability p lying to its right.

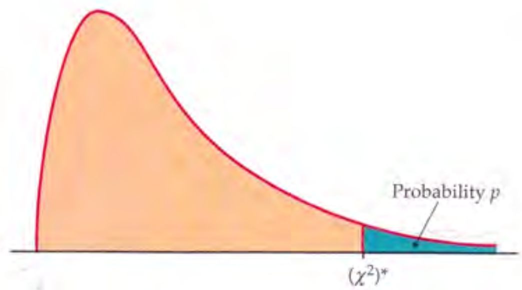


TABLE F

χ^2 distribution critical values

df	.25	.20	.15	.10	.05	.025	.02	.01	.005	.0025	.001	.0005
	Tail probability p											
1	1.32	1.64	2.07	2.71	3.84	5.02	5.41	6.63	7.88	9.14	10.83	12.12
2	2.77	3.22	3.79	4.61	5.99	7.38	7.82	9.21	10.60	11.98	13.82	15.20
3	4.11	4.64	5.32	6.25	7.81	9.35	9.84	11.34	12.84	14.32	16.27	17.73
4	5.39	5.99	6.74	7.78	9.49	11.14	11.67	13.28	14.86	16.42	18.47	20.00
5	6.63	7.29	8.12	9.24	11.07	12.83	13.39	15.09	16.75	18.39	20.51	22.11
6	7.84	8.56	9.45	10.64	12.59	14.45	15.03	16.81	18.55	20.25	22.46	24.10
7	9.04	9.80	10.75	12.02	14.07	16.01	16.62	18.48	20.28	22.04	24.32	26.02
8	10.22	11.03	12.03	13.36	15.51	17.53	18.17	20.09	21.95	23.77	26.12	27.87
9	11.39	12.24	13.29	14.68	16.92	19.02	19.68	21.67	23.59	25.46	27.88	29.67
10	12.55	13.44	14.53	15.99	18.31	20.48	21.16	23.21	25.19	27.11	29.59	31.42
11	13.70	14.63	15.77	17.28	19.68	21.92	22.62	24.72	26.76	28.73	31.26	33.14
12	14.85	15.81	16.99	18.55	21.03	23.34	24.05	26.22	28.30	30.32	32.91	34.82
13	15.98	16.98	18.20	19.81	22.36	24.74	25.47	27.69	29.82	31.88	34.53	36.48
14	17.12	18.15	19.41	21.06	23.68	26.12	26.87	29.14	31.32	33.43	36.12	38.11
15	18.25	19.31	20.60	22.31	25.00	27.49	28.26	30.58	32.80	34.95	37.70	39.72
16	19.37	20.47	21.79	23.54	26.30	28.85	29.63	32.00	34.27	36.46	39.25	41.31
17	20.49	21.61	22.98	24.77	27.59	30.19	31.00	33.41	35.72	37.95	40.79	42.88
18	21.60	22.76	24.16	25.99	28.87	31.53	32.35	34.81	37.16	39.42	42.31	44.43
19	22.72	23.90	25.33	27.20	30.14	32.85	33.69	36.19	38.58	40.88	43.82	45.97
20	23.83	25.04	26.50	28.41	31.41	34.17	35.02	37.57	40.00	42.34	45.31	47.50
21	24.93	26.17	27.66	29.62	32.67	35.48	36.34	38.93	41.40	43.78	46.80	49.01
22	26.04	27.30	28.82	30.81	33.92	36.78	37.66	40.29	42.80	45.20	48.27	50.51
23	27.14	28.43	29.98	32.01	35.17	38.08	38.97	41.64	44.18	46.62	49.73	52.00
24	28.24	29.55	31.13	33.20	36.42	39.36	40.27	42.98	45.56	48.03	51.18	53.48
25	29.34	30.68	32.28	34.38	37.65	40.65	41.57	44.31	46.93	49.44	52.62	54.95
26	30.43	31.79	33.43	35.56	38.89	41.92	42.86	45.64	48.29	50.83	54.05	56.41
27	31.53	32.91	34.57	36.74	40.11	43.19	44.14	46.96	49.64	52.22	55.48	57.86
28	32.62	34.03	35.71	37.92	41.34	44.46	45.42	48.28	50.99	53.59	56.89	59.30
29	33.71	35.14	36.85	39.09	42.56	45.72	46.69	49.59	52.34	54.97	58.30	60.73
30	34.80	36.25	37.99	40.26	43.77	46.98	47.96	50.89	53.67	56.33	59.70	62.16
40	45.62	47.27	49.24	51.81	55.76	59.34	60.44	63.69	66.77	69.70	73.40	76.09
50	56.33	58.16	60.35	63.17	67.50	71.42	72.61	76.15	79.49	82.66	86.66	89.56
60	66.98	68.97	71.34	74.40	79.08	83.30	84.58	88.38	91.95	95.34	99.61	102.7
80	88.13	90.41	93.11	96.58	101.9	106.6	108.1	112.3	116.3	120.1	124.8	128.3
100	109.1	111.7	114.7	118.5	124.3	129.6	131.1	135.8	140.2	144.3	149.4	153.2

Source: (Moore et. al, 2012)

Page intentionally left blank.

Appendix G: T Distribution Critical Values

Page intentionally left blank.

Table entry for p and C is the critical value t^* with probability p lying to its right and probability C lying between $-t^*$ and t^*.

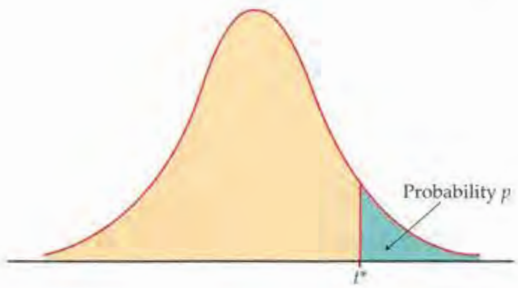


TABLE D

t distribution critical values

df	Upper-tail probability p											
	.25	.20	.15	.10	.05	.025	.02	.01	.005	.0025	.001	.0005
1	1.000	1.376	1.963	3.078	6.314	12.71	15.89	31.82	63.66	127.3	318.3	636.6
2	0.816	1.061	1.386	1.886	2.920	4.303	4.849	6.965	9.925	14.09	22.33	31.60
3	0.765	0.978	1.250	1.638	2.353	3.182	3.482	4.541	5.841	7.453	10.21	12.92
4	0.741	0.941	1.190	1.533	2.132	2.776	2.999	3.747	4.604	5.598	7.173	8.610
5	0.727	0.920	1.156	1.476	2.015	2.571	2.757	3.365	4.032	4.773	5.893	6.869
6	0.718	0.906	1.134	1.440	1.943	2.447	2.612	3.143	3.707	4.317	5.208	5.959
7	0.711	0.896	1.119	1.415	1.895	2.365	2.517	2.998	3.499	4.029	4.785	5.408
8	0.706	0.889	1.108	1.397	1.860	2.306	2.449	2.896	3.355	3.833	4.501	5.041
9	0.703	0.883	1.100	1.383	1.833	2.262	2.398	2.821	3.250	3.690	4.297	4.781
10	0.700	0.879	1.093	1.372	1.812	2.228	2.359	2.764	3.169	3.581	4.144	4.587
11	0.697	0.876	1.088	1.363	1.796	2.201	2.328	2.718	3.106	3.497	4.025	4.437
12	0.695	0.873	1.083	1.356	1.782	2.179	2.303	2.681	3.055	3.428	3.930	4.318
13	0.694	0.870	1.079	1.350	1.771	2.160	2.282	2.650	3.012	3.372	3.852	4.221
14	0.692	0.868	1.076	1.345	1.761	2.145	2.264	2.624	2.977	3.326	3.787	4.140
15	0.691	0.866	1.074	1.341	1.753	2.131	2.249	2.602	2.947	3.286	3.733	4.073
16	0.690	0.865	1.071	1.337	1.746	2.120	2.235	2.583	2.921	3.252	3.686	4.015
17	0.689	0.863	1.069	1.333	1.740	2.110	2.224	2.567	2.898	3.222	3.646	3.965
18	0.688	0.862	1.067	1.330	1.734	2.101	2.214	2.552	2.878	3.197	3.611	3.922
19	0.688	0.861	1.066	1.328	1.729	2.093	2.205	2.539	2.861	3.174	3.579	3.883
20	0.687	0.860	1.064	1.325	1.725	2.086	2.197	2.528	2.845	3.153	3.552	3.850
21	0.686	0.859	1.063	1.323	1.721	2.080	2.189	2.518	2.831	3.135	3.527	3.819
22	0.686	0.858	1.061	1.321	1.717	2.074	2.183	2.508	2.819	3.119	3.505	3.792
23	0.685	0.858	1.060	1.319	1.714	2.069	2.177	2.500	2.807	3.104	3.485	3.768
24	0.685	0.857	1.059	1.318	1.711	2.064	2.172	2.492	2.797	3.091	3.467	3.745
25	0.684	0.856	1.058	1.316	1.708	2.060	2.167	2.485	2.787	3.078	3.450	3.725
26	0.684	0.856	1.058	1.315	1.706	2.056	2.162	2.479	2.779	3.067	3.435	3.707
27	0.684	0.855	1.057	1.314	1.703	2.052	2.158	2.473	2.771	3.057	3.421	3.690
28	0.683	0.855	1.056	1.313	1.701	2.048	2.154	2.467	2.763	3.047	3.408	3.674
29	0.683	0.854	1.055	1.311	1.699	2.045	2.150	2.462	2.756	3.038	3.396	3.659
30	0.683	0.854	1.055	1.310	1.697	2.042	2.147	2.457	2.750	3.030	3.385	3.646
40	0.681	0.851	1.050	1.303	1.684	2.021	2.123	2.423	2.704	2.971	3.307	3.551
50	0.679	0.849	1.047	1.299	1.676	2.009	2.109	2.403	2.678	2.937	3.261	3.496
60	0.679	0.848	1.045	1.296	1.671	2.000	2.099	2.390	2.660	2.915	3.232	3.460
80	0.678	0.846	1.043	1.292	1.664	1.990	2.088	2.374	2.639	2.887	3.195	3.416
100	0.677	0.845	1.042	1.290	1.660	1.984	2.081	2.364	2.626	2.871	3.174	3.390
1000	0.675	0.842	1.037	1.282	1.646	1.962	2.056	2.330	2.581	2.813	3.098	3.300
z^*	0.674	0.841	1.036	1.282	1.645	1.960	2.054	2.326	2.576	2.807	3.091	3.291
	50%	60%	70%	80%	90%	95%	96%	98%	99%	99.5%	99.8%	99.9%
	Confidence level C											

Source: (Moore et. al, 2012)

Page intentionally left blank.

Appendix H: Water Quality Data

Page intentionally left blank.

Sample	TC (MPN/100mL)	Risk Level	TC LRV	E.coli (MPN/100 mL)	Risk Level	E.coli LRV	Turbidity (NTU)	Turbidity % Removal
C-1 STRD	691.0	Very High	1.26	0.999	No Action	0.00	13.49	-43.74
C-1 FLTRD	38.4	Intermediate		0.999	No Action		19.39	
C-2 STRD	816.4	Very High	2.61	7.4	Low	0.87	171.89	20.94
C-2 FLTRD	2.0	Low		0.999	No Action		135.89	
C-3 STRD	7,590.0	Very High	0.82	517.2	Very High	2.71	320.89	76.66
C-3 FLTRD	1,153.0	Very High		0.999	No Action		74.89	
C-4 STRD	>241,960	Very High	x	6.3	Low	0.80	43.09	82.99
C-4 FLTRD	1,299.7	Very High		0.999	No Action		7.33	
C-5 STRD	>241,960	Very High	x	117.8	Very High	-0.01	47.29	77.18
C-5 FLTRD	123.6	Very High		119.8	Very High		10.79	
C-6 STRD	9,060.0	Very High	0.47	30.1	Intermediate	1.48	56.69	84.11
C-6 FLTRD	3,076.0	Very High		0.999	No Action		9.01	
C-7 STRD	8,840.0	Very High	1.73	65.7	Intermediate	1.82	49.39	91.23
C-7 FLTRD	165.8	Very High		0.999	No Action		4.33	
C-8 STRD	10,190.0	Very High	2.39	178.5	Very High	1.17	22.39	72.67
C-8 FLTRD	41.7	Intermediate		12.2	Intermediate		6.12	
C-9 STRD	488.4	Very High	2.69	8.5	Low	0.93	19.69	66.48
C-9 FLTRD	1.0	Low		0.999	No Action		6.60	
C-10 STRD	>241,960	Very High	x	43.1	Intermediate	x	119.89	x
C-10 FLTRD	N/A	N/A		N/A	N/A		N/A	
C-11 STRD	6,131.0	Very High	-0.45	5.1	Low	-0.50	186.89	74.54
C-11 FLTRD	17,329.0	Very High		16.0	Low		47.59	
C-12 STRD	2,143.0	Very High	1.08	613.1	Very High	2.79	506.89	92.43
C-12 FLTRD	178.5	Very High		0.999	No Action		38.39	
C-13 STRD	27,550.0	Very High	1.65	111.8	Very High	0.66	39.59	92.19
C-13 FLTRD	613.1	Very High		24.3	Intermediate		3.09	
C-14 STRD	15,531.0	Very High	1.43	17.1	Intermediate	-0.13	36.49	84.54
C-14 FLTRD	579.4	Very High		23.1	Intermediate		5.64	
C-15 STRD	7,701.0	Very High	1.00	27.9	Intermediate	1.45	34.79	79.30
C-15 FLTRD	771.0	Very High		0.999	No Action		7.20	
C-16 STRD	613.1	Very High	1.52	0.999	No Action	0.00	30.09	22.93
C-16 FLTRD	18.7	Intermediate		0.999	No Action		23.19	
C-17 STRD	12,033.0	Very High	3.08	64.4	Intermediate	1.81	133.89	47.43
C-17 FLTRD	10.0	Low		0.999	No Action		70.39	
C-18 STRD	17,329.0	Very High	2.75	101.2	Very High	2.01	125.89	74.43
C-18 FLTRD	31.0	Intermediate		0.999	No Action		32.19	
C-19 STRD	5,172.0	Very High	1.38	79.4	Intermediate	1.90	226.89	63.38
C-19 FLTRD	214.2	Very High		1.0	Low		83.09	
C-20 STRD	4,352.0	Very High	1.20	78.4	Intermediate	1.89	49.59	26.82
C-20 FLTRD	275.5	Very High		1.0	Low		36.29	

Sample	TC (MPN/100mL)	Risk Level	TC LRV	E.coli (MPN/100 mL)	Risk Level	E.coli LRV	Turbidity (NTU)	Turbidity % Removal
C-21 STRD	7,270.0	Very High	1.59	133.3	Very High	2.13	62.29	70.16
C-21 FLTRD	185.0	Very High		0.999	No Action		18.59	
C-22 STRD	29,090.0	Very High	2.52	139.6	Very High	2.14	108.89	66.12
C-22 FLTRD	88.4	Intermediate		1.0	Low		36.89	
C-23 STRD	6,867.0	Very High	2.51	90.5	Intermediate	1.96	124.89	63.90
C-23 FLTRD	21.3	Intermediate		0.999	No Action		45.09	
C-24 STRD	2,481.0	Very High	1.09	53.8	Intermediate	1.73	35.19	3.41
C-24 FLTRD	201.0	Very High		0.999	No Action		33.99	
C-25 STRD	5,475.0	Very High	2.36	307.6	Very High	2.49	40.99	83.09
C-25 FLTRD	24.1	Intermediate		1.0	Low		6.93	
C-26 STRD	8,164.0	Very High	0.95	93.3	Intermediate	1.97	42.69	77.61
C-26 FLTRD	920.8	Very High		1.0	Low		9.56	
C-27 STRD	29,090.0	Very High	3.76	410.0	Very High	1.91	39.69	85.16
C-27 FLTRD	4.999	Low		4.999	Low		5.89	
C-28 STRD	114,500.0	Very High	2.89	310.0	Very High	1.79	71.19	93.31
C-28 FLTRD	148.0	Very High		4.999	Low		4.76	
C-29 STRD	53,800.0	Very High	0.54	100.0	Intermediate	1.30	49.19	81.09
C-29 FLTRD	15,531.0	Very High		4.999	Low		9.30	
C-30 STRD	129,970.0	Very High	3.31	<100	N/A	x	84.89	35.93
C-30 FLTRD	63.0	Intermediate		4.999	Low		54.39	
C-31 STRD	173,290.0	Very High	4.24	100.0	Intermediate	1.30	15.49	-111.04
C-31 FLTRD	10.0	Low		4.999	Low		32.69	
C-32 STRD	27,550.0	Very High	x	<100	N/A	x	86.29	54.70
C-32 FLTRD	>241,960	Very High		41.0	Intermediate		39.09	
C-33 STRD	4,140.0	Very High	0.63	200.0	Very High	1.60	69.79	43.42
C-33 FLTRD	960.0	Very High		4.999	Low		39.49	
C-34 STRD	13,540.0	Very High	1.16	<100	N/A	x	126.89	32.00
C-34 FLTRD	933.0	Very High		4.999	Low		86.29	
C-35 STRD	13,140.0	Very High	1.21	520.0	Very High	2.02	132.89	87.59
C-35 FLTRD	813.0	Very High		4.999	Low		16.49	
C-36 STRD	36,540.0	Very High	3.07	100.0	Intermediate	1.30	159.87	30.02
C-36 FLTRD	31.0	Intermediate		4.999	Low		111.87	
C-37 STRD	5,200.0	Very High	0.32	300.0	Very High	0.76	69.57	57.06
C-37 FLTRD	2,489.0	Very High		52.0	Intermediate		29.87	
C-38 STRD	2,010.0	Very High	2.60	<100	N/A	x	122.87	51.44
C-38 FLTRD	4.999	Low		0.999	No Action		59.67	
C-39 STRD	2,790.0	Very High	0.32	310.0	Very High	1.79	80.97	77.07
C-39 FLTRD	1,350.0	Very High		4.999	Low		18.57	
C-40 STRD	1,890.0	Very High	1.98	200.0	Very High	1.60	122.87	63.89
C-40 FLTRD	20.0	Intermediate		4.999	Low		44.37	

Sample	TC (MPN/100mL)	Risk Level	TC LRV	E.coli (MPN/100 mL)	Risk Level	E.coli LRV	Turbidity (NTU)	Turbidity % Removal
C-41 STRD	111,990.0	Very High	2.72	860.0	Very High	2.24	55.77	86.57
C-41 FLTRD	213.0	Very High		4.999	Low		7.49	
C-42 STRD	120,330.0	Very High	2.95	970.0	Very High	2.29	64.37	81.40
C-42 FLTRD	135.0	Very High		4.999	Low		11.97	
C-43 STRD	1,870.0	Very High	0.75	100.0	Intermediate	0.70	39.47	87.28
C-43 FLTRD	336.0	Very High		20.0	Intermediate		5.02	
C-44 STRD	26,130.0	Very High	2.38	520.0	Very High	1.72	67.27	27.35
C-44 FLTRD	108.0	Very High		10.0	Low		48.87	
C-45 STRD	7,540.0	Very High	2.89	100.0	Intermediate	2.00	177.86	79.11
C-45 FLTRD	9.8	Low		0.999	No Action		37.16	
C-46 STRD	1,723.0	Very High	3.24	4.999	Low	0.70	37.76	33.37
C-46 FLTRD	1.0	Low		0.999	No Action		25.16	
C-47 STRD	9,060.0	Very High	-0.68	410.0	Very High	1.91	189.86	71.79
C-47 FLTRD	43,520.0	Very High		4.999	Low		53.56	
C-48 STRD	86,640.0	Very High	2.47	12,997.0	Very High	3.11	183.86	62.60
C-48 FLTRD	292.0	Very High		10.0	Low		68.76	
C-49 STRD	4,800.0	Very High	0.90	310.0	Very High	2.49	173.86	53.15
C-49 FLTRD	598.0	Very High		0.999	No Action		81.46	
C-50 STRD	517,200.0	Very High	3.68	750.0	Very High	2.88	181.86	54.88
C-50 FLTRD	108.6	Very High		1.0	Low		82.06	
C-51 STRD	12,460.0	Very High	1.96	200.0	Very High	2.00	171.86	44.45
C-51 FLTRD	135.4	Very High		2.0	Low		95.46	
C-52 STRD	5,650.0	Very High	-0.15	100.0	Intermediate	1.39	169.86	45.86
C-52 FLTRD	7,915.0	Very High		4.1	Low		91.96	
C-53 STRD	5,540.0	Very High	0.61	100.0	Intermediate	1.00	176.86	78.88
C-53 FLTRD	1,355.0	Very High		10.0	Low		37.36	
C-54 STRD	36,540.0	Very High	x	<100	N/A	x	190.87	78.59
C-54 FLTRD	>241,960	Very High		4.999	Low		40.87	
C-55 STRD	1,203,300.0	Very High	5.47	200.0	Very High	2.30	199.87	80.90
C-55 FLTRD	4.1	Low		0.999	No Action		38.17	
C-56 STRD	43,520.0	Very High	2.77	100.0	Intermediate	1.30	198.87	87.49
C-56 FLTRD	74.0	Intermediate		4.999	Low		24.87	
C-57 STRD	3,090.0	Very High	2.88	200.0	Very High	2.30	184.87	34.62
C-57 FLTRD	4.1	Low		0.999	No Action		120.87	
C-58 STRD	6,370.0	Very High	0.55	200.0	Very High	1.60	333.87	92.82
C-58 FLTRD	1,777.0	Very High		4.999	Low		23.97	
C-59 STRD	12,110.0	Very High	-0.27	200.0	Very High	0.59	705.87	70.69
C-59 FLTRD	22,470.0	Very High		52.0	Intermediate		206.87	
C-60 STRD	13,760.0	Very High	0.24	200.0	Very High	-0.41	712.87	-3.51
C-60 FLTRD	7,940.0	Very High		520.0	Very High		737.87	

Sample	TC (MPN/100mL)	Risk Level	TC LRV	E.coli (MPN/100 mL)	Risk Level	E.coli LRV	Turbidity (NTU)	Turbidity % Removal
C-61 STRD	16,160.0	Very High	1.05	410.0	Very High	0.26	896.87	97.93
C-61 FLTRD	1,450.0	Very High		226.0	Very High		18.57	
C-62 STRD	5,830.0	Very High	1.97	<100	N/A	x	557.87	43.02
C-62 FLTRD	63.0	Intermediate		4.999	Low		317.87	
C-63 STRD	20,640.0	Very High	0.95	520.0	Very High	2.02	980.85	89.72
C-63 FLTRD	2,310.0	Very High		4.999	Low		100.85	
C-64 STRD	>2,419,600	Very High	x	1,830.0	Very High	2.56	925.85	95.81
C-64 FLTRD	816.0	Very High		4.999	Low		38.75	
C-65 STRD	48,840.0	Very High	4.08	100.0	Intermediate	2.00	897.85	75.96
C-65 FLTRD	4.1	Low		1.0	Low		215.85	
C-66 STRD	24,890.0	Very High	0.32	1,100.0	Very High	2.34	927.85	94.96
C-66 FLTRD	12,033.0	Very High		4.999	Low		46.75	
C-67 STRD	10,190.0	Very High	2.40	200.0	Very High	1.60	940.85	86.94
C-67 FLTRD	41.0	Intermediate		4.999	Low		122.85	
C-68 STRD	14,830.0	Very High	1.90	100.0	Intermediate	1.30	646.85	78.84
C-68 FLTRD	185.0	Very High		4.999	Low		136.85	
C-69 STRD	12,010.0	Very High	3.08	<100	N/A	x	675.85	85.08
C-69 FLTRD	10.0	Low		4.999	Low		100.85	
C-70 STRD	2,560.0	Very High	1.92	410.0	Very High	1.91	640.85	85.06
C-70 FLTRD	31.0	Intermediate		4.999	Low		95.75	
C-71 STRD	104,620.0	Very High	1.86	<100	N/A	x	167.85	14.89
C-71 FLTRD	1,430.0	Very High		4.999	Low		142.85	
C-72 STRD	61,310.0	Very High	-0.45	200.0	Very High	1.60	162.86	67.91
C-72 FLTRD	173,290.0	Very High		4.999	Low		52.26	
C-73 STRD	>2,419,600	Very High	x	19,040.0	Very High	4.28	66.06	31.64
C-73 FLTRD	0.999	No Action		0.999	No Action		45.16	
C-74 STRD	8,840.0	Very High	1.23	410.0	Very High	1.61	766.86	83.46
C-74 FLTRD	520.0	Very High		10.0	Low		126.86	
C-75 STRD	14,500.0	Very High	1.19	750.0	Very High	2.18	779.86	83.99
C-75 FLTRD	933.0	Very High		4.999	Low		124.86	
C-76 STRD	10,540.0	Very High	1.13	1,100.0	Very High	2.04	806.86	94.81
C-76 FLTRD	789.0	Very High		10.0	Low		41.86	
C-77 STRD	6,440.0	Very High	2.09	630.0	Very High	2.10	229.85	51.77
C-77 FLTRD	52.0	Intermediate		4.999	Low		110.85	
C-78 STRD	13,090.0	Very High	2.63	980.0	Very High	2.29	218.85	51.63
C-78 FLTRD	31.0	Intermediate		4.999	Low		105.85	
C-79 STRD	30,760.0	Very High	3.49	1,610.0	Very High	2.51	413.85	96.34
C-79 FLTRD	10.0	Low		4.999	Low		15.15	
C-80 STRD	2,419,600.0	Very High	4.77	1,100.0	Very High	2.34	233.85	60.04
C-80 FLTRD	41.0	Intermediate		4.999	Low		93.45	

<table>
<tr><th>Sample</th><th>TC (MPN/100mL)</th><th>Risk Level</th><th>TC LRV</th><th>E.coli (MPN/100 mL)</th><th>Risk Level</th><th>E.coli LRV</th><th>Turbidity (NTU)</th><th>Turbidity % Removal</th></tr>
<tr><td>C-81 STRD</td><td>630.0</td><td>Very High</td><td rowspan="2">0.71</td><td><100</td><td>N/A</td><td rowspan="2">x</td><td>193.85</td><td rowspan="2">36.11</td></tr>
<tr><td>C-81 FLTRD</td><td>122.0</td><td>Very High</td><td>4.999</td><td>Low</td><td>123.85</td></tr>
<tr><td>C-82 STRD</td><td>23,820.0</td><td>Very High</td><td rowspan="2">3.08</td><td>3,450.0</td><td>Very High</td><td rowspan="2">2.84</td><td>1000.00</td><td rowspan="2">77.12</td></tr>
<tr><td>C-82 FLTRD</td><td>20.0</td><td>Intermediate</td><td>4.999</td><td>Low</td><td>228.85</td></tr>
<tr><td>C-83 STRD</td><td>23,820.0</td><td>Very High</td><td rowspan="2">2.29</td><td>3,050.0</td><td>Very High</td><td rowspan="2">2.79</td><td>986.85</td><td rowspan="2">92.75</td></tr>
<tr><td>C-83 FLTRD</td><td>122.0</td><td>Very High</td><td>4.999</td><td>Low</td><td>71.55</td></tr>
<tr><td>C-84 STRD</td><td>29,090.0</td><td>Very High</td><td rowspan="2">1.20</td><td>3,450.0</td><td>Very High</td><td rowspan="2">1.93</td><td>946.85</td><td rowspan="2">93.08</td></tr>
<tr><td>C-84 FLTRD</td><td>1,850.0</td><td>Very High</td><td>41.0</td><td>Intermediate</td><td>65.55</td></tr>
<tr><td>C-85 STRD</td><td>27,550.0</td><td>Very High</td><td rowspan="2">4.44</td><td>3,010.0</td><td>Very High</td><td rowspan="2">3.48</td><td>874.84</td><td rowspan="2">67.56</td></tr>
<tr><td>C-85 FLTRD</td><td>0.999</td><td>No Action</td><td>0.999</td><td>No Action</td><td>283.84</td></tr>
<tr><td>C-86 STRD</td><td>19,350.0</td><td>Very High</td><td rowspan="2">4.29</td><td>2,490.0</td><td>Very High</td><td rowspan="2">3.40</td><td>1000.00</td><td rowspan="2">86.82</td></tr>
<tr><td>C-86 FLTRD</td><td>0.999</td><td>No Action</td><td>0.999</td><td>No Action</td><td>131.84</td></tr>
<tr><td>C-87 STRD</td><td>17,800.0</td><td>Very High</td><td rowspan="2">4.25</td><td>1,890.0</td><td>Very High</td><td rowspan="2">3.28</td><td>954.84</td><td rowspan="2">92.74</td></tr>
<tr><td>C-87 FLTRD</td><td>0.999</td><td>No Action</td><td>0.999</td><td>No Action</td><td>69.34</td></tr>
</table>