Investigations on household filtration in Haiti

Final Report

Tufts University

CDC Centers for Disease Control and Prevention

Suggested Citation: Rayner J and Lantagne D. 2014. *Investigations on household filtration in Haiti: Final Report*. Tufts University for the Centers for Disease Control and Prevention.

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EXECUTIVE SUMMARY

On January 12, 2010, a 7.0 magnitude earthquake struck 17 kilometers southwest of Port-au-Prince, Haiti. Ten months after the earthquake, in October 2010, cholera was introduced into Haiti, beginning an outbreak that has since claimed over 8,500 lives and caused over 700,000 cases. Before the earthquake and cholera outbreak, numerous household water treatment and safe storage (HWTS) options were promoted in Haiti to reduce diarrheal disease in households without access to water and sanitation infrastructure. The majority of the HWTS options distributed were consumable chlorine-based options, such as tablet and liquid chlorine. These household chlorination programs have been shown to be effective at improving stored household drinking water quality and reducing the burden of diarrhea in Haiti.

HWTS options were promoted more intensely after the earthquake. A study conducted in the acute and sustained earthquake response period found that effective use of HWTS options was associated with: 1) targeting households with contaminated water, such as households using unimproved sources; 2) providing an HWTS method that effectively treated the water; and, 3) providing the HWTS method to a population who was familiar with the product, willing to use it, received training in its use, received the necessary supplies to use it, and received a safe storage container.

In general, durable HWTS options, such as filters, have been less commonly implemented in Haiti, leading to a concurrently smaller evidence-base to understand how to effectively implement filtration programs to achieve the desired outcomes of household water quality improvement and health impact. Since the advent of the ongoing cholera outbreak, there has been increased interest in filtration options; as they are perceived to be a durable HWTS option that might be used more consistently than a consumable option. Approximately 140,000 Biosand, Ceramic, Sawyer, and Lifestraw Filters have been documented to have been distributed in Haiti since 2010, which is likely an underestimate of the total number distributed. At a household size of 5-6 persons, the number of filters known to have been distributed could reach almost 1 million people. Given this scale, it is critical to understand how effective these filters are at improving water quality in user households in Haiti.

Thus, the goal of the "Investigations of Household Filtration in Haiti" project was to provide technical assistance and monitoring and evaluation support to further scale-up filtration-based HWTS options to respond to cholera in Haiti, particularly on Ceramic Filters, which are considered one of the most promising filtration options. To complete this goal, four investigations were conducted:

1. The development of an international Certification Scheme for ceramic manufacturing facilities;
2. Site visits to the four ceramic manufacturing facilities (one in Haiti, two in the Dominican Republic, and one in Guatemala) that have provided filters in response to the earthquake and cholera emergencies in Haiti to develop and trial the application of the Certification Scheme;
3. Laboratory investigation of the efficacy at removing *E. coli* of sample non-silver and silver-coated Ceramic Filters from the four facilities visited; and,
4. A survey of households that were documented to receive Ceramic, Biosand, and Sawyer Filters in Haiti.

Investigation 1: International Certification Scheme

Ceramic Filters are manufactured by pressing a mixture of locally-sourced clay and a burn-out material, such as sawdust or rice husk, into the filter shape. After pressing, filters are allowed to dry before being fired to a ceramic state (~800-900°C). The specific clay to burn-out material ratio is determined during facility establishment by testing prototype filters for flow rate and microbiological efficacy. Throughout production, each filter's flow rate is measured to evaluate production consistency and filters that meet quality control criteria are packaged for sale or distribution. Silver is added as a bacteriocide, either by application to fired filters or by inclusion in the filter mixture. Although the manufacturing process is not complicated, a number of critical variables need to be controlled in order to ensure the quality of the final product. A key challenge is maintaining manufacturing quality control standards in decentralized production facilities.

The number of filter manufacturing facilities worldwide has grown from 35 in 2009 to >50 in 2013, and continued growth is anticipated. To address building quality control concerns, the Ceramics Manufacturing Working Group (CMWG) – comprised of individuals from governmental and non-governmental organizations, filter facilities, filter consultants and academia – developed the "Best Practice Recommendations for Local Manufacturing of Ceramic Pot Filters for Household Water Treatment" manual to guide facilities in manufacturing efficacious filters. This manual includes a summary of existing research, recommendations to facilities based on that research in the seven production categories of source materials and processing, filter production, firing, silver, quality control, packaging, and health and safety, and recommendations for future research.

To develop a Certification Scheme, we translated the recommendations of the 187-page Best Practice manual into two tools:

- A facility questionnaire, for a facility to fill out before an external evaluator arrives at the facility; and,
- A facility evaluation protocol, for an external assessor to complete during an on-site visit.

These tools were developed and trialed during four facility assessments, refined after the trials, and applied to the four visited facilities. The completed assessments will be provided to the facilities for their comments and responses. At the next meeting of the CMWG, the primary topic of conversation will be: 1) discussion, potential for acceptance, and validation of the processes developed in this work; 2) a decision on whether to certify the facilities or not; and, 3) how to seek funding to continue this process and conduct certification of the >50 facilities worldwide.

Investigation 2: Ceramic Manufacturing Facility Site Visits

Approximately 1-week long site visits were conducted in the four facilities that have provided Ceramic Filters to emergency response programs in Haiti: 1) FilterPure in the Dominican Republic; 2) Atabey in the Dominican Republic; 3) Ecofiltro in Guatemala; and 4) FilterPure in Haiti. Subsequent to the site visits, the Certification Scheme protocol was completed, and *required* and *recommended* changes to facility practices to receive certification were developed. The Haiti FilterPure facility was subsequently visited two additional times.

Investigation 3: Laboratory Testing

The goals of the laboratory testing of filter efficacy were to: 1) determine *E. coli* removal efficacy to see if filters meet the Best Practice manual recommendation of >2 LRV (log reduction value, >99%) without silver application; 2) determine whether silver concentration in initial filtered water and after ~3 filter volumes of water has been flushed through the filter meets WHO drinking water guideline values for silver (<0.1 mg/L); and, 3) confirm filters meet facility and Best Practice manual flow rate criteria.

Ten filters were tested for flow rate, *E. coli* LRV, and silver elution. All filters except one test filter met facility flow rate criteria. The filter without silver from DR FilterPure and the filters with silver from DR FilterPure and Haiti FilterPure all met Best Practice manual guidelines for LRV of *E. coli* (>2 LRV in filters without silver or with silver fired into the mixture). The DR Atabey filters without silver and the Guatemala Ecofiltro filters with and without silver did not meet this guideline. The low LRVs seen in both the Guatemala Ecofiltro and DR Atabey filters could in part be due to the relatively large burn-out material particle size used at these facilities.

All silver samples from filters with silver were below WHO guideline values except the first flush of one Haiti FilterPure filter, which subsequently met guidelines at the second flush testing. Haiti FilterPure effluent water had 0.056 mg/L of arsenic, which is above the WHO guideline value of 0.01 mg/L. Arsenic has been detected in filtered water from Ceramic Filters manufactured in other countries, and is attributed to arsenic present in the raw clay material leaching into water during filtration. It is recommended to research this in the future.

The results from the facility visits and laboratory testing confirm prior work that there is significant manufacturing variation at facilities that impacts filter efficacy. The DR FilterPure facility came the closest to meeting the two critical criteria for certification: 1) microbiological efficacy standards (>2 LRV of spiked *E. coli* in the laboratory) and, 2) manufacturing practices suggestive of consistent production. Minor required and recommended recommendations have been developed for formal Certification of this facility. The DR Haiti facility also met microbiological efficacy standards, and also needs to verify consistency of manufacturing. The DR Atabey and Guatemala Ecofiltro facilities met neither criterion.

It is thus recommended that the Haiti FilterPure facility work on the process improvements that would allow Certification and that the Guatemala Ecofiltro facility work to determine the potential cause – be it large size sawdust used in processing, kiln management, or another production issue – that is the root of the low microbiological efficacy. It is anticipated that once addressed, both facilities could proceed with Certification. It is not anticipated that DR Atabey will proceed with Certification.

Investigation 4: Household Survey

Each known Ceramic, Biosand, Sawyer, and Lifestraw Filter program in Haiti was asked if they would like to participate in the evaluation. Subsequently, 50 households were randomly selected from distribution lists provided by the program for household surveying and water quality testing.

A total of 223 households documented to have received a Ceramic, Biosand, or Sawyer Filter in Haiti in five different programs were surveyed, of the 250 randomly selected households. The five programs evaluated varied from emergency distributions with no follow-up to longer-term development programs with consistent training, follow-up, and oversight. Source waters used by filter recipients varied from highly clean kiosk and tap water to very contaminated surface and canal water sources. The vast majority of respondents reported knowing that water can make you sick, and consistent with other research, the main reasons water was considered safe to drink is that it has been 'treated'. The vast majority of households used a 5-gallon storage container. Latrine presence in respondent households was low (56%), and handwashing stations and soap presence was very low (5%-11%).

The majority of households in all but one of the programs reported using the filter in the last week, but concerningly, 82% of respondents reported drinking unfiltered water when out of the home (for Biosand and Sawyer Filters) or when there was no filtered water (for Ceramic Filters). Overall, 58% of households reported having water treated with the filter they had received at the time of the unannounced visit (range 27%-80%). Effective use (the percentage of the target population that improved their water from contaminated (≥1 CFU *E.* coli/100 mL) to uncontaminated <1 CFU *E. coli*/100 mLwith the filter) was low to medium across all programs – from 0% to 34%. Using a breakpoint of <10 *E. coli*/100 mL for the effective use metric (which is not currently supported by the Haitian government) more accurately reflects the risk reduction in programs where untreated water had high levels of *E. coli* contamination, and changes the effective use numbers to 9-45%.

While it is not possible to directly compare the programs, some themes that have been noted in the literature before also appear in this study. Well-manufactured Ceramic Filters were more effective at treating water to <1 *E. coli*/100 mL, but were more likely to break. Additionally, recipients were more likely to report they drank untreated water because there was no filtered water, which is likely attributable to the relatively lower flow rate of Ceramic Filters. Biosand Filters were less effective at treating water to <1 *E. coli*/100 mL, and treated water was more likely to be used for uses in addition to drinking water, which is likely attributable to the higher flow rate.

Summary

This multi-investigation study allowed us to obtain significant information on the efficacy and effectiveness of filters distributed in response to cholera in Haiti. Our results both confirm and expand upon previous results and highlight the difficulty in ensuring HWTS programs reach their goal of improving the microbiological quality of household stored drinking water and reduce the risk of diarrheal disease. While filters can be an effective option to improve the microbiological quality of household stored drinking water in Haiti, the results presented herein are sobering and highlight the factors necessary to reach this goal, including: 1) quality controlled (local) manufacturing; and, 2) distribution of filters to those with contaminated source water with sufficient training and materials for recipients to use the filters correctly and consistently to improve the quality of their household drinking water. Our results also document the first known instance of lower quality Ceramic Filters (from DR Atabey) leading to poor reduction of *E. coli* at the household level in users of that filter.

The results presented herein highlight the need to have a Certification Scheme for ceramic manufacturing facilities to ensure quality control of locally-manufactured products. These results will be: 1) distributed to the participating facilities for review and comment; and, 2) presented and discussed at the Ceramic Manufacturing Working Group meeting at the Water and Health: Where Science Meets Policy meeting in October to determine how to move forward with a Certification Scheme process.

However, the results are also promising, as it is anticipated that three of the four production facilities could obtain Certification with achievable improvements, and there was high levels of use and medium levels of effective use in programs (such as CWH Biosand and PWW Biosand) that provided filters to recipient households with training, education, and follow-up. This result is very similar to previous results showing that HWTS can, if implemented in certain ways, be a mechanism to reduce the risk of diarrheal disease in users.

In order to have a successful HWTS filter program, each step needs to be well-implemented, including: 1) production or importation and subsequent distribution of a filter that successfully removes *E. coli* from the source waters to be treated; and, 2) distribution of that filter to households that are sufficiently trained to use the filter to improve the quality of their household stored drinking water. To our knowledge, this is the first study that investigated that entire chain – from production to household use.

The investigations completed within this work and presented herein highlight the difficulties in using household filters to improve the microbiological quality of household stored water and reduce the risk of diarrheal disease and cholera transmission in Haiti. While programs that provide a high-quality product to users with contaminated water who are trained and supported in using that filter can be successful, the overall results are consistent with previous research in Haiti: successful HWT programs depend on community support and structure. It is unrealistic to distribute a durable product and assume that product is being used to improve water quality in the absence of an ongoing support structure. The challenge will be in supporting the scaling-up of these community-based projects to reach a scale to reduce the risk of diarrheal disease and cholera transmission in Haiti.

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Acronyms

ASSLHA	Association San Lucas d'Haiti
CDC	Centers for Disease Control and Prevention
CFU	Colony Forming Unit
CHW	Community Health Worker
CMWG	Ceramics Manufacturing Working Group
CWH	Clean Water for Haiti
DR	Dominican Republic
FCR	Free Chlorine Residual
HH	Household
HWTS	Household Water Treatment and Safe Storage
INGO	International Non-governmental Organization
IRB	Institutional Review Board
LRV	Log Reduction Value
mg/L	Milligram per Liter
mL	Milliliter
MPN	Most Probable Number
L	Liter
LRV	Log Reduction Value
NGO	Non-governmental Organization
NTU	Nephelometric Turbidity Unit
PWW	Pure Water for the World
SES	Socio-economic Status
UNC W&H Conference	University of North Carolina's 'Water and Health: Where Science Meets Policy' Conference
WASH	Water, Sanitation, and Hygiene
WHO	World Health Organization

Acknowledgements

The authors would like to thank the following people, without whom this work could not have been completed:

- The four Ceramic Filter facilities who graciously allowed us to visit and evaluate their production practices, including: 1) Ecofiltro in Guatemala, particularly Philip Wilson and Lic. Fernando Mazariegos; 2) FilterPure in the Dominican Republic, particularly Lisa Ballantine, Brad Ponack, and Radahmes Carela; 3) FilterPure in Haiti, particularly Patrice Tallyrand and David Cadot; and, 4) Atabey in the Dominican Republic, particularly Jesús Manuel and Patricia Guillén.
- The survey respondents, who welcomed us into their homes and took their valuable time to answer our questions during the emergency contexts.
- Myriam Leandre Joseph, who translated documents and coordinated Haitian Institutional Review Board application.
- The survey enumerators - including Wilguens (Junior) Fecu, Johnny Verdieu, Marco Louis, Jeffrey Fecu, Marie-Carme Georges - who collectively interviewed almost 250 respondents.
- The community leaders who assisted the enumerators in locating households within their community.
- The local organizations who graciously allowed us to evaluate their programs, including Clean Water for Haiti, Pure Water for the World, Haiti FilterPure, Asociation San Lucas d'Haiti, Waves for Water, GOALS, Asosiyasyon Plante Mango Komin Leyogan, the Building Goodness Foundation, and CODEP.
- Michael Ritter and Fritz Pierre-Louis, who provided logistical support during the survey.
- Chris Rock, of Tufts University Environmental Health & Safety Office, for removing waste and coordinating laboratory testing.
- Anjuliee Mittleman, who completed silver analysis of the filtered water from the laboratory filters.
- Anna Murray, who assisted in conducting the survey in Haiti.
- Ariel Brantz, who assisted with data entry and analysis of the survey data.
- The Centers for Disease Control and Prevention and staff, especially Molly Patrick, Thomas Handzel and Rick Gelting without whose vision and organization this study would not have been possible.

1 Household Filtration in Haiti

1.1 Background on Household Filtration in Haiti

On January 12, 2010, a 7.0 magnitude earthquake struck 17 kilometers southwest of Port-au-Prince, Haiti. Nearly one-third of Haiti's population, almost three million people, were affected[1]. An estimated 222,517 people died and 310,928 were injured[2]. Ten months after the earthquake, in October 2010, cholera was introduced into Haiti, sparking an outbreak that has since claimed over 8,500 lives and caused over 700,000 cases[3]. These two emergencies – which occurred in an already complex political emergency context – stimulated international interest in establishing water and sanitation infrastructure in Haiti. The United Nations has launched a 10-year, 2.27 billion USD plan to eradicate cholera on the island of Hispaniola, which is currently in the initial stages of funding and implementing.

1.1.1 Household Water Treatment and Safe Storage in Haiti Before the Emergencies

Evidence suggests the use of household water treatment and safe storage (HWTS) options can improve household water quality and reduce diarrheal disease in households without access to water and sanitation infrastructure[4, 5]. As a result, UNICEF and the World Health Organization (WHO) recommend HWTS as part of a comprehensive strategy to prevent diarrheal disease in low-income settings[6].

Before the earthquake and cholera outbreak, numerous consumable and durable HWTS options were promoted in Haiti[7]. Consumable products used included chlorine tablets, liquid chlorine, and powdered chlorine sold in the market or distributed by non-governmental organizations (NGOs) and relief organizations. Durable products used included imported ceramic and multi-barrier filters and locally-manufactured Biosand Filters. Boiling has not been widely promoted in Haiti due to extensive deforestation, and flocculant/disinfectant and locally-made Ceramic Filter programs had been discontinued before the earthquake due to lack of consumer uptake and poor-quality raw materials for manufacturing, respectively.

Overall, 45.6% of urban and 24.4% of rural populations in Haiti self-reported treating drinking water before the earthquake, the large majority (42.0% and 21.2% of the overall population) by adding bleach or other chlorine-based products[8]. Small percentages (0.1-3.4%) reported boiling, filtering, solar disinfection, settling and decanting, using commercial flocculant/disinfectants, adding citrus, and/or other approaches.

Research completed specifically on household chlorination programs in Haiti has found they can be effective at improving stored household drinking water quality and reducing the burden of diarrhea[9, 10]. In a study of the Jolivert Safe Water for Families program, which has been selling sodium hypochlorite solution (chlorine) and conducting household visits in rural Haiti since 2002, 56% of participants (versus 10% of controls) had free chlorine residuals (FCR) between 0.2 and 2.0 mg/L, indicating correct water treatment[9]. Additionally, significantly fewer children <5 years of age in participant households had had an episode of diarrhea in the previous 48 hours (32% versus 52%; p<0.001) with a 59% reduced odds of diarrhea (odds ratio = 0.41, 95% confidence interval = 0.21-0.79). Diarrheal disease reduction in this long-term program was comparable with those seen in short-term randomized, controlled interventions, suggesting that household chlorination can be an effective long-term water treatment strategy in Haiti.

Research has also been completed on Biosand Filters that were installed in the Artibonite Valley of Haiti. An initial study of 107 recipient household conducted in 2005 found that Biosand Filters had been in use for an average of 2.5 years, and reduced *E. coli* by 98.5% and turbidity by 85% on average[11]. A follow-up study was conducted in 2011, in the same area and program, with 55 households that had filters installed between 1999 and 2010. This study found that 53% of the filters were still in use, reducing the *E. coli,* on average, by 1.1 LRV (log reduction value)[12]. Statistical analysis found that use remained >85% for up to seven years after installation. While this follow-up study was limited by the fact non-randomized, link-tracing sampling (which preferentially samples households still using their filters) was conducted, it does show that long-term use of Biosand Filters is also possible in Haiti.

1.1.2 Household Water Treatment in Haiti after the Emergencies

Safe drinking water is an immediate priority in most emergencies[13]. When normal water supplies are interrupted or compromised due to natural disasters, complex emergencies, or outbreaks, responders have often encouraged affected populations to boil or disinfect their drinking water to ensure its microbiological integrity. A review found that HWTS can be effective at improving water quality in small-scale, non-acute, high-diarrheal disease risk emergencies when training and materials were provided to recipients, adequate product stocks were maintained, and chlorine dosage was appropriate[14]. There is also some evidence that populations that take up HWTS in response to an emergency may continue to follow the practice long term – due to increased awareness of HWTS methods, experience using the interventions, and improved access to HWTS options – after the emergency. In one study, 49% of 115 recipient households visited had a working filter 16 months after Ceramic Filter distribution in the Dominican Republic[15]. A study conducted 2-3 years after Ceramic Filters were distributed in response to the 2004 Tsunami, in Sri Lanka found that 71% of households self-reported Ceramic Filter use that day or the day before the household visit[16]. In both studies, the authors noted the importance and the difficulty of establishing distribution mechanisms to provide or sell replacement parts to users.

A study undertaken with support from UNICEF and Oxfam Great Britain to investigate the contribution of HWTS in the Haiti earthquake response during both the acute emergency phase (weeks 3-8 following the earthquake) and the longer-term recovery phase (about 10 months later) found that take-up and effective use of HWTS options distributed during earthquake response varied significantly[10, 17]. Four programs that distributed HWTS methods within eight weeks of emergency onset were investigated, including: 1) continuous community-based distribution of Aquatabs brand chlorine tablets (Aquatabs) and safe storage containers with training and oversight by community health workers (CHWs) to 2,880 families by a local pre-existing NGO; 2) non-food item kit distribution of Aquatabs with no training by an international NGO to families in spontaneous settlements in Port-au-Prince; 3) distribution of 350 Ceramic Filters with one training by an international NGO;

and 4) distribution of 238 Biosand Filters with one training by a pre-existing local NGO. The highest effective use (63%) was observed in the Aquatabs distribution program with CHW support. The characteristics of this program that led to success were: 1) it targeted households with contaminated water, such as those households using unimproved sources; 2) it provided an HWTS method that effectively treated the water; and, 3) the recipient population was familiar with the product, willing to use it, received training in its use, received the necessary supplies to use it, and received a safe storage container. When one of these factors was missing effective use dropped considerably, such as lack of contaminated water in the Ceramic Filter distribution, where the majority of recipients used improved water supplies (effective use of 20%); a working product in the Biosand filter distribution, where Biosand Filters were incorrectly installed (effective use of 8%); or, lack of sufficient training and follow-up in the Aquatabs distribution in spontaneous settlements (effective use of 13%). Overall, higher effective use rates were associated with programs that were underway in Haiti before the emergency, had a plan at initial distribution for program continuation, and distributed products with CHW support and a safe storage container.

These results held true in another study in the heavily-cholera affected Artibonite region, where there was free distribution of Aquatabs without CHW support[18]. While 85.1% of respondents reported preferring disinfection treatment methods, only 31.6% of households had a HWTS product in the home at the time of the unannounced survey. Additionally, while 38.3% of households reported treated drinking water in the household at the time of the unannounced survey only 30.4% of those households (12.7% of the total surveyed households) had FCR in their drinking water.

1.1.3 HWT Filtration Options in Haiti

In general, filtration options have been less commonly implemented in Haiti, leading to a concurrently smaller evidence-base to determine how to effectively implement filtration programs to achieve the outcomes of household water quality improvement and health impact. Since the advent of the ongoing cholera outbreak, there has been increased interest in filtration options; because it is perceived a durable HWTS option (like a filter that remains in the home) might be used more consistently than a consumable option (such as chlorine, which must be distributed or purchased regularly). The four types of filters promoted in Haiti after the cholera outbreak – Biosand, Ceramic, Sawyer, and Lifestraw – are briefly described below.

Biosand Filters

The Biosand Filter is a slow-sand filter adapted for use in the home. The version of the Biosand Filter most widely implemented consists of layers of sand and gravel in a concrete or plastic container approximately 0.9 meters tall, and 0.3 meters square. The water level is maintained at 5-6 cm above the sand layer by setting the height of the outlet pipe. This shallow water layer allows a bioactive layer to grow on top of the sand, which contributes to the reduction of disease-causing organisms. A diffuser plate with holes in it is placed on the top of the sand layer to prevent disruption of the biolayer when water is added to the system. To use the Biosand Filter, users simply pour water into the Biosand Filter and collect finished water out of the outlet pipe into a bucket. Although a number of small NGOs distribute a small number of Biosand Filters in Haiti, the most active NGOs distributing Biosand Filters are Pure Water for the World (PWW) and Clean Water for Haiti (CWH).

PWW has been working in Haiti since before the earthquake but has changed strategies multiple times. PWW initially distributed Biosand Filters to households, then moved to distributing tanker truck water after the earthquake, then focused on Biosand Filter distributions in schools. Since evaluations have shown the school strategy was challenging due to lack of use during school holidays, PWW modified their strategy and is now working in four communities doing community-based Biosand Filter distribution with ongoing CHW support. They have distributed approximately 1,250 Biosand Filters under this new model. PWW also distributed 3,300 of the FilterPure Ceramic Filters to households in spontaneous settlements.

CWH has been working in Haiti with Biosand Filters for over 10 years. They manufacture up to 30 concrete-cased Biosand Filter's per day. They have a database that includes records of 10,259 installed filters, beginning with the 2005 installations. CWH received 300 filters from the DR Atabey facility, noted they were of poor quality, but due to donor requirements distributed these filters to families in the mountains that they could not reach with the heavy and difficult to transport concrete Biosand Filters.

Ceramic Filters

Locally manufactured Ceramic Filters are an ~10L capacity, silver treated ceramic filtering element that suspends in a safe storage container fitted with a tap for dispensing treated water. Users pour water into the filter, wait for the water to flow through the filter into the receptacle, and dispense filtered water from the tap. The filters are produced in-country at ceramics manufacturing facilities.

Historically, there has been strong interest in establishing Ceramic Filter production facilities in Haiti, although both organizations that attempted to establish production in Haiti before the earthquake ceased operations due to lack of high-quality production materials. After the earthquake and cholera, filters were imported from three regional facilities for emergency response:

1. From the Ecofiltro facility in Guatemala, who flew with 1,200 filters to Haiti to complete the training with recipients;
2. From the FilterPure facility in the Dominican Republic, who sold 12,482 filters to NGOs in Haiti; and,
3. From the Atabey facility in the Dominican Republic, where 300 filters were purchased by Potters for Peace and transported to CWH for distribution. Additionally, the FilterPure facility in the Dominican Republic worked to establish and provide technical assistance to a new Ceramic Filter facility in Jacmel, Haiti, which has since sold 20,000 filters in Haiti.

Sawyer Filters

The Sawyer PointOne Filter is a microfilter consisting of hollow fibers bundled in a U-shape inside a plastic casing (Sawyer Products Inc., Safety Harbor, FL, USA). The PointOne is promoted for recreational use, disaster relief, and HWTS in developing countries. For household use, users attach the PointOne in-line with a delivery hose to a 20-Liter bucket. Water flows via gravity into the casing inlet, through the 0.1-micron (µm) porous fiber walls into the hollow membrane tubes, and exits the tubes into a second storage container. Users are instructed to backwash the filter when flow slows, using the provided syringe and clean water.

Fritz Pierre-Louis is the distributor in Haiti for Sawyer Products, and notes that there have been approximately 70,000-80,000 Sawyer filters distributed in Haiti since the earthquake. The vast majority (52,500) were sold to Compassion International, who installed them across all 10 Departments (States) in Haiti. Additionally, Waves for Water has purchased 20,000 Sawyer filters for installation in the Central Plateau. Lastly, 15,000 filters have been sold to individuals, NGOs, and MINUSTAH. It was noted that sales of Sawyer Filters have decreased recently.

Lifestraw Filters

LifeStraw Filters use hollow fiber technology to filter water. Lifestraw has distributed three types of Lifestraw filters in Haiti since the earthquake, through distributor Luc Hilhorst. Approximately 10,000 Lifestraw Filters (discontinued), 15,000 Lifestraw Family Filters, and 200 Lifestraw community filters have been sold to NGOs and distributed to households or communities. The vast majority of the Lifestraw Family Filters were distributed by World Vision International and handed out without training to households in spontaneous settlements. Luc Hilhorst mentioned that sales have decreased recently.

Figure 1: Images of Filters Distributed in Haiti (Biosand, Ceramic, Sawyer, and Lifestraw)

Summary

In summary, we can count that approximately 140,000 Biosand, Ceramic, Sawyer, and Lifestraw Filters have been distributed in Haiti. The actual number of filters distributed is likely much higher, as the distributions able to be counted are not representative of all emergency response in Haiti. At a household size of 5-6 persons per household, the above filters could reach almost 1 million people. Given the scale of the distributions, it is critical to know how effective the filters are at improving water quality in user households in Haiti.

1.2 The Investigation of Household Filtration in Haiti Project

To goal of the "Investigations of Household Filtration in Haiti" project was to provide technical assistance and monitoring and evaluation support to further scale-up filtration-based HWTS options to respond to cholera in Haiti, particularly on Ceramic Filters, which are considered one of the most promising HWT filtration options but that may be of variable quality depending on local manufacturing conditions. To complete this goal four investigations were conducted: 1) the development of an international Certification Scheme for Ceramic Filter manufacturing facilities; 2) site visits to the four ceramic manufacturing facilities (in Haiti, Dominican Republic, and Guatemala) that have provided filters in response to the earthquake and cholera emergencies in Haiti to trial application of the Certification Scheme; 3) laboratory investigation of the efficacy in removing *E. coli* of sample non-silver and silver-coated Ceramic Filters from the four facilities visited; and, 4) a household survey of recipients of Ceramic, Biosand, and Sawyer Filters in Haiti. The results from these four investigations are detailed herein.

2 Research Methods

2.1 Development of Certification Scheme

Ceramic Filters are a promising HWTS option, as in laboratory investigations they effectively remove >99% of protozoan[19, 20] and 90-99.99999% of bacterial organisms from drinking water[19-21]. Virus removal remains a challenge, with results ranging from 63-99.9%[19, 20]. In the field, water treated by Ceramic Filters is often improved to the WHO low-risk classification of <10 CFU *E. coli* /100 mL[22-24]. Filter use has been associated with a 49% reduction in diarrheal disease among users[23].

A key challenge of this technology is maintaining manufacturing quality control standards in decentralized manufacturing facilities. Filters are manufactured by pressing a mixture of locally-sourced clay and a burn-out material, such as sawdust or rice husk, into the filter shape. After pressing, filters are allowed to dry before being fired to a ceramic state (~800-900°C). The specific clay to burn-out material ratio is determined during facility establishment by testing prototype filters for flow rate and microbiological efficacy. Throughout production, filter flow-rate is measured and filters that meet the facility-established acceptable flow rate are packaged for sale or distribution. Silver is added as a bacteriocide, either by application to fired filters or included in the filter mixture. Although the manufacturing process is not complicated, a number of critical variables need to be controlled in order to ensure the quality of the final product.

Manufacturing practices vary widely both across and within facilities, including: 1) 82% of facilities modify their filter mixture formula regularly or as needed; 2) the type of wood varies at almost half of the facilities that use sawdust as a burn-out material; 3) the filter shape, capacity (6-12L), depth (22.5-29cm), and wall thickness (1-3cm) varies between facilities; 4) flow rate test protocols vary in method, the number of filters tested, and accepted flow rate ranges (1-3 L/hr minimum to 2-5 L/hr maximum); and 5) not all facilities test their filters for microbiological effectiveness[25]. Facility visits and anecdotal information suggest that manufacturing variation has resulted in filters of varying quality reaching the market.

Existing data describing relationships between input variables (clay, burn-out materials), filter characteristics (porosity and flow rate) and quality criteria (flow rate, *E. coli* reduction) is limited and, in some cases, contradictory. Filters manufactured with the same clay, burn-out material screened to the same size, and the same clay:burn-out mixture ratio but with different burn-out material types resulted in flow rate variation[26]. Results are consistent that porosity and flow rate can be increased by increasing the burn-out material to clay ratio, but are contradictory as to the impact on bacteria removal[26-29]. Bloem et al. found no significant change in filters with flow rates increased to 8-10 L/hr, while Lantagne et al. found total coliform removal decreased to <99% with flow rates above 1.7 L/hr. Overall, studies conducted to date have been limited by investigation of one filter recipe, insufficient production documentation, and/or non-systematic approaches to investigating input variables, filter characteristics, and quality criteria.

The number of filter facilities has grown from 35 in 2009 to >50 in 2013, and continued growth is anticipated. Thus, standardized quality control guidelines are essential to responsibly scale-up decentralized Ceramic Filter production. To address quality control concerns, the Ceramics Manufacturing Working Group (CMWG) – comprised of individuals from governmental and non-governmental organizations, filter facilities, filter consultants and academia – developed the "Best Practice Recommendations for Local Manufacturing of Ceramic Pot Filters for Household Water Treatment" manual to guide facilities in manufacturing efficacious filters[30]. This manual includes a summary of existing research, recommendations to facilities based on that research in seven categories (source materials and processing, filter production, firing, silver, quality control, packaging, and health and safety), and recommendations for future research.

The CMWG meets yearly, at a dedicated side-event session during the University of North Carolina's 'Water and Health: Where Science Meets Policy' Conference (UNC W&H Conference). The last meeting, in October 2013, was dedicated to discussing the idea of developing a Certification Scheme for ceramic manufacturing facilities. The approximately 25 attendees were in strong support of a Certification Scheme, both to ensure quality control of Ceramic Filters that reach the market and because individual facilities (particularly in China and Yemen) were suffering due to knock-off products of lower quality being sold at a lower price in the market that they had created. The final consensus of the meeting was to support the development of this scheme.

To develop a Certification Scheme, we translated the recommendations of the 187-page Best Practice manual into two tools:

1. A ceramic manufacturing facility questionnaire, for a facility to fill out before an external evaluator arrives at the facility; and.
2. A ceramic manufacturing facility evaluation protocol, for an external assessor to follow during an on-site assessment visit.

These tools were concurrently developed and trialed during the four facility site visit assessments, as detailed in the next section.

2.2 Ceramic Manufacturing Facility Site Visits

Site visits were conducted at the four facilities that have provided Ceramic Filters to emergency response programs in Haiti: 1) FilterPure in the Dominican Republic; 2) Atabey in the Dominican Republic; 3) Ecofiltro in Guatemala; and 4) FilterPure in Haiti. At each approximately 1-week long site visit, the following activities were completed: 1) talking about the proposed Certification Scheme; 2) talking about their production methods; 3) observing filter production, including photographic documentation; and, 4) concurrently developing and applying the draft Certification Scheme protocol. Subsequent to the site visits, the Certification Scheme protocol was completed, and 'required' and 'recommended' changes to facility practices to receive certification were drafted. The Haiti FilterPure facility was visited two more times to finalize the Certification Scheme and begin to consider implementing required and recommended changes.

2.3 Laboratory Testing of Filter Efficacy

The goals of the laboratory testing of filter efficacy were to: 1) Determine *E. coli* removal efficacy to see if filters meet the Best Practice manual recommendation of >2 LRV (>99%) without silver application; 2) Determine whether silver concentration in initial filtered water and after ~3 filter volumes of water is flushed through the filter meets WHO drinking water guideline values for silver (0.1 mg/L); and, 3) Confirm filters meet facility and Best Practice manual flow rate criteria.

DR FilterPure, DR Atabey, and Guatemala Ecofiltro each provided three Ceramic Filters with silver applied, and three Ceramic Filters without silver applied. Haiti FilterPure provided three Ceramic Filters with silver applied. All filters were transported to the Environmental Sustainability Laboratory at Tufts University.

Upon arrival at the laboratory, the physical parameters of all filters (including thickness and dry and saturated weights) were measured. Then, filters with silver applied were tested for silver concentration in filtered water. Silver concentration was measured using a calibrated inductively coupled plasma-mass spectrometry machine on a sample collected after 1-3 Liters of MilliQ water had flowed through the filter.

Filters were then rinsed with boiled water, suspended on a specially-designed rack suspended over a scale with a bucket, and filled with tap water. After three pore volumes of tap water had flowed through the filter, influent water and filtered water were measured for pH and temperature. Filters were then refilled with tap water, and allowed to flow for one hour. Flow rate was calculated by dividing the weight of water by the time of filtration.

After the testings described above, filters were tested for efficacy using *E. coli (*ATCC® 25922) spiked in deionized water. The *E. coli* was prepared by using a sterile inoculating loop to streak an agar plate with thawed *E. coli* stock; the agar plate was incubated at 35°C for 12-24 hours. A flask of broth was then inoculated with an isolated colony from the agar plate and incubated at 35°C for 4-5 hours. A 1-mL sample of the innoculated broth was analyzed using a GeneQuant 100 spectrophotometer to estimate the volume of broth necessary to spike the Ceramic Filters with approximately 10^7 CFU *E. coli*/100 mL. This estimated reading was then confirmed using the IDEXX Quantitray method and Colilert media for quantifying the most probable number (MPN) of *E. coli*/100 mL. Three pore volumes of the spiked water were allowed to filter through the filter, and then an autoclaved funnel was used to guide 100-mL of sample water into a sterile beaker. The IDEXX method (as described above) was used to quantify *E. coli* in the filtered water. This process was repeated after allowing three pore volumes of deionized water to flow through the filter. Filtered water samples were collected and analyzed to ensure no *E. coli* remained in filtered water; filters were baked for 15 minutes at 100°C if contamination was seen. LRV's were calculated based on *E. coli* concentrations in spiked and filtered water.

Due to the potential for metal contamination in the filtered water, all filtered water from silver applied filters was collected in dedicated waste containers and collected by the Environmental Health & Safety Office of Tufts University. As per University policy, some of this filtered water was tested at Triumverate Environmental for arsenic, barium, cadmium, chlroium, lead mercury, selenium, and silver using analytical method 1,6010C.

2.4 Survey of Filter Recipients in Haiti

Each of the Ceramic, Biosand, Sawyer, and Lifestraw Filter programs described in the introduction were contacted and asked if they would like to participate in the survey. Each program that agreed to participate was asked to provide a distribution list of households that had received the filter. Randomly selected recipients from programs that provided distribution lists were visited for an unannounced survey and water quality testing. This study protocol was approved by the Tufts University and Haitian Institutional Review Boards.

2.4.1 Household Surveys

For each program that provided distribution lists, a representative geographical region was selected for sampling. From that representative geographical region, 50 households were randomly selected for household surveying. The household survey was comprised of a general section administered to all households consisting of 48 questions on household demographics, water knowledge, attitudes, and practices, and water treatment, followed by a section specific to the type of filter received consisting of 46-48 questions on filter use, maintenance, cleaning, and satisfaction. The survey was translated into, and administered in, Haitian Kreyol. Enumerators were trained during a two-day instruction session that included training on how to randomly selecting households, obtain consent, deliver questions, record answers, and prevent bias. Informed consent was obtained before verbally administering the survey, and the survey took about 40 minutes to administer in each household.

2.4.2 Water Quality Testing

Household stored water was tested for *E. coli*, Total Coliforms, and turbidity.

The presence of *E. coli* in drinking water indicates the water is fecally contaminated and is unsafe for drinking. During the household survey, the respondent was asked: "May I have a cup of water you would drink?" The respondent was then asked if the water provided was treated. If the respondent replied 'yes', the enumerator asked if there was untreated water collected from the same source in the home. A 125-mL sample of available untreated and treated household stored water was collected aseptically into a sterile Whirl-pak™ bag and stored on ice at no more than 4°C. Additionally, a 'direct from filter' sample was also collected if there was source water available to pour into the Biosand Filter or Sawyer Filter, or if there was treated water in the safe storage container of the Ceramic Filter. This sample was collected to determine if there was recontamination during storage. For Biosand and Sawyer Filters, this water was collected directly from a sterilized outflow pipe; for Ceramic Filters this was collected from a sterilized tap.

Samples from households that had treated and untreated water samples were tested for *E. coli* and Total Coliforms using membrane filtration. Samples were diluted appropriately with sterile buffered water, filtered aseptically through a 45-µm Millipore filter on a portable Millipore filtration stand, placed in a plastic Petri dish with a pad soaked with mColiBlue24 media, and incubated at 35-37°C for 24 hours. For quality control, negative controls of boiled water were sampled every 20 plates, plates were considered accurate only if there were <200 colonies, and 10% of samples were duplicated.

E. coli results were used to calculate the effective use of the filters by the target population. For this metric, households must have not only been users, but also must have been reliant on contaminated sources for drinking water (≥1 CFU/100 mL *E. coli*) and used the filters to reduce the microbiological contamination to a safe 'no risk' level (<1 CFU/100 mL). Effective use was calculated as the percent of the population that reported using the filters multiplied by the percent of households with ≥1 CFU/100 mL before treatment (in the untreated stored household water) and <1 CFU/100 mL (in their reported treated stored household water).

Turbidity samples were obtained from the excess water in the Whirl-Pak sampling bags not used in microbiological sampling on an ad-hoc basis and measured with a calibrated Lamotte 2020 Turbidimeter within 24 hours of collection.

2.4.3 Data Recording and Analysis

The survey and water quality data were entered into Microsoft Excel (Redmond, WA, USA). Analysis was conducted in SPSS, version 21.

3 Results

3.1 Development of Certification Scheme

An Excel-based questionnaire form for ceramic manufacturing facilities was developed, and is attached as Annex A. The objective of the questionnaire is to obtain information regarding filter manufacturing before a site visit assessment is conducted, so that a site visit assessor can arrive prepared to complete the assessment. The form is divided into 10 sections, including: background information, raw materials and processing, filter production, firing, quality control evaluations, filtered water testing, silver, packaging, documentation, and health and safety.

A facility evaluation protocol was developed in Word, and is attached as Annex B. This form follows the same sections as the questionnaire form, but is meant to be completed by the assessor during the site visit. As such, additional sections are included on observed practices and required and recommended changes necessary to obtain certification.

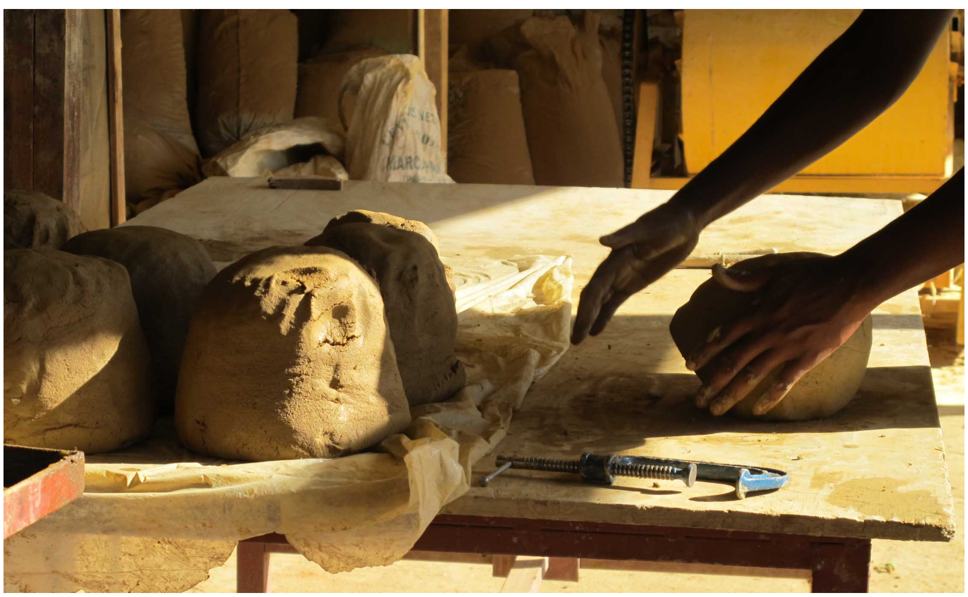

Figure 2: Preparing Clay for Pressing

3.2 Ceramic Manufacturing Facility Site Visits

Four ceramic manufacturing facilities that have produced filters used in emergency response in Haiti were identified, including: 1) the FilterPure facility in the Dominican Republic; 2) the Atabey facility in the Dominican Republic; 3) the Ecofiltro facility in Guatemala; and, 4) the FilterPure facility in Haiti.

3.2.1 Background Information

Each of the four facilities was visited a minimum of one time during the course of the project (Table 1). Please note that the full facility visit reports are included as Annex D, E, F, and G. Additionally, the filled-out site assessment protocol worksheet from the DR Haiti facility visit is included as Annex C.

Production was directly observed at all facilities, except DR Atabey, which was not in production despite confirmation they would be during the scheduled visits (Table 1). The most established facility (Guatemala Ecofiltro) was first established in the 1980's, mechanized in 2004, and had a purpose-built large facility specially designed in 2013. The newest facility is the Haiti FilterPure facility, established in 2010. The production capacity ranges from 150-4,800 per month, all facilities except DR Atabey produce continuously. The number of employees ranges from 6-59. The cost per filter ranges from 28-71 USD per filter; please note the Haiti FilterPure cost includes delivery and community education. The primary distribution models of all facilities except Guatemala Ecofiltro is sales to NGO's who distribute the filters for free or at highly subsidized rates. The Guatemala Ecofiltro model is to work with communities to complete distribution and education of a Ceramic Filter at no cost. Then, they follow-up with the families to provide training to save money each month to make payments towards a replacement filter each year. Approximately 32,000 filters have been, to date, distributed from these facilities into Haiti as part of emergency response.

Figure 3: Images of the Facilities Visited (clockwise from top left: DR FilterPure, DR Atabey, Guatemala Ecofiltro, Haiti FilterPure)

Table 1: Facility Information

	DR FilterPure	DR Atabey	Guatemala Ecofiltro	Haiti FilterPure
Date(s) of site visits	December 28, 2013- January 3, 2014 March 19-25, 2014	January 3, 2014 March 15-29, 2014	November 25- December 2, 2013	January 4-14, 2014 July 22-29, 2014 August 18-20, 2014
Production observed	Yes	No	Yes	Yes
Date established	2006	2006	1980's (potter's wheel) 2004 (hydraulic press) 2013 (new facility)	2010
Contact person	Lisa Ballantine lisaballantine@aol.com	Guillén Family hermanosguillen@ hotmail.es	Philip Wilson pwilsonarzu@gmail.com	Patrice Tallyrand marcel.leopold.patrice@ gmail.com
Production capacity (per month)	3,000 filters	150 filters	4,800 filters	1,200 filters
Number of employees	6	6	59	13
Primary distribution model	Sales to NGOs who distribute for free or at subsidized cost.	Produce only on-demand when receive an order.	Community-based group distribution, education, and monthly payments for annual replacement. Urban sales subsidize rural sales.	Sales to NGOs who distribute for free.
Price per filter	46 USD 28 USD (only element)	28 USD (retail) 25 USD (wholesale) 19 USD (only element)	39 USD (retail) 26 USD (only element)	January 2014 47 USD (<100) 42 USD (>100) 25 USD (only element) August 2014 71 USD
Number of filters distributed in Haiti for emergency response	12,482	300	1,200	20,000

Figure 4: Images of Filters From each Facility (DR FilterPure, DR Atabey, Guatemala Ecofiltro, Haiti FilterPure)

3.2.2 Raw Materials and Processing / Silver

All of the facilities have hammer mills to assist in processing the raw clay, electric mixers to assist in creating a well-mixed mixture of raw materials, manual or automatic presses to press the clay into the shape, and kilns to fire the filters (Table 2). Only two facilities have pugmills, which can be used to make the filter mixture more homogenous. Electrical supply at the facilities is either grid or generator, with two facilities noting inconsistent electricity impacting production. When electricity is not available, DR Atabey can and does complete all mixing by hand. All facilities have a water supply, but only two facilities have tested that water.

Table 2: Equipment at Four Ceramic Manufacturing Facilities Visited

	DR FilterPure	DR Atabey	Guatemala Ecofiltro	Haiti FilterPure
Hammer mill	4 (2 used, raised)	1	1 (raised)	2 (one not in use)
Mixer	1	1	1	1
Press	1 (automatic, triple mold)	2 (manual, not assembled)	1 (automatic, double mold)	2 (manual, 1 not in use)
Pugmill	0	1 (not used in production)	1	0
Kiln	1 for filters (plus 2 wood fueled and 2 small gas kilns)	1 for filters (plus 2 others)	2 for filters	1 for filters (plus 2 small electric kilns)
Electricity	Grid	Grid (inconsistent) plus rented generator	Grid (consistent)	Grid (inconsistent)
Water source	Rainwater stored in large tank, tanker truck water	Tanker truck water	Private well on site	Private well on site
Water testing	For *E. coli*	No information	Twice per year	Not completed
Other	Wheeled cart	--	Bobcat, wheeled carts	Wheeled carts

Two facilities have reserved a single seam of clay to ensure reliability of their clay source (DR FilterPure and Guatemala Ecofiltro), with Haiti FilterPure working with a single mine, and DR Atabey having variable clay depending on location in the mine (Table 3). Each facility tests their clay in some manner but does not carry out regular evaluations on clay to monitor consistency. The clay is milled at all facilities (if electricity is available) and sieved only at DR FilterPure and Haiti FilterPure. Reprocessed clay is included in the mixture at two facilities. All facilities use sawdust as the burn-out material, but only two facilities work with sawdust from a single type of wood. The sawdust is milled at two facilities and sieved at all four facilities. The sieve mesh size varies significantly between the facilities – from 10 to 32 mesh. Please note a lower mesh allows larger particles to fall through the sieve. Liquid colloidal silver, silver nanoparticles in solution, and powdered silver nanoparticles are used to make the silver solution for application. Silver is, locally-obtained or imported from the United States or Spain. Silver is applied by brushing, dipping, or firing it into the filter mixture.

Table 3: Raw Materials and Processing at Four Ceramic Manufacturing Facilities Visited

	DR FilterPure	DR Atabey	Guatemala Ecofiltro	Haiti FilterPure
Clay source	Single reserved seam	Single source, varies depending on place in mine	Single source, purchased mine	Single source
Clay testing	Visual and tactile for uniformity of color, high-plasticity, and low sand content	Evaluation methods not provided	Each lot tested with sample filters (65% success rate needed)	Visually for non-uniform clumps
Clay milled	Yes (5 mm screen)	If electricity	Yes (5 mm screens)	Yes (5 mm screen)
Clay sieved	32 Mesh	No	No	20-25 Mesh
Reprocessed clay included	Yes (unfired, max of 3%)	Yes	No	Yes (fired, to make grog included regularly)
Burn-out	Sawdust	Sawdust	Sawdust	Sawdust
Burn-out sources	Contracted mill (pine only, not contaminated)	Variable (acacia or pine)	Contracted mill (pine, sustainable, not contaminated)	Mixed (pine, hardwood)
Burn-out milled	Yes	No	No	Equipment broken
Burn-out sieved	Yes, 32 Mesh	Yes, >12 Mesh	Yes, 10 Mesh	Yes, 20-25 Mesh
Additional materials in filter mixture	Silver	None	None	Grog, silver
Silver source	Proprietary	Spain	Guatemala/USA	Proprietary
Silver type	Nanoparticles in solution	Powder	Colloidal silver	Nanoparticles in solution
Silver concentration	50% solution of 80 nanometer particles	~70% silver	3.5% solution	50% solution of 80 nanometer particles
Silver added	Proprietary	Estimated	400 mL of 0.09% solution	Proprietary
Silver application method	In mix, fired in	Submerged	Brushed on	In mix, fired in

3.2.3 Filter Production

The raw material mixture ratios used in filter production varied across the four facilities, with all facilities reporting changing their ratios by manufacturing a certain number of prototype filters and testing them for flow rate criteria (Table 4). In addition, two facilities have a filter tested with the new ratio at a laboratory. The batch size ranges from 6-31 filters, and all filters are stamped with a serial number and (in three of four facilities) a logo.

Table 4: Filter Production at Four Ceramic Manufacturing Facilities Tested

	DR FilterPure	DR Atabey	Guatemala Ecofiltro	Haiti FilterPure
Raw material mixture ratio	93 kg clay, 23 kg sawdust, 45 Liters of water, silver	Water and sawdust measured by volume, clay by weight. No current ratio	27 kg clay, 4.3 kg sawdust, 12.5 L water	84 kg clay, 30 kg sawdust, 58-60 kg water, 15 kg grog, silver
Variation in mixture	When flow rate falls out of target	Adjusted with each new clay shipment	Adjusted with each new clay shipment	Water added varies with humidity
Procedure to change raw material mixture ratio	Manufacture 2-3 filters from 3 different recipes, test flow rate and select recipe that most meets flow criteria	Manufacture 10 filters of 10 recipes, test flow rate and select recipe that most meets quality criteria	Manufacture and flow rate test 50 filters, change if 90% pass 1-2 L/hr flow criteria; one filter tested at a laoratory	Manufacture and test 30 filters for flow rate
Filters per batch	25	No information	6	31
Press	Automatic, triple-mold	Manual, single mold	Automatic, double mold	Manual, single mold
Pressure gauge	Yes, 2100 PSI	No	No	No
Stamp	Serial number, logo	Serial number	Coded serial number (date-number-letter-number), logo	Serial number, logo

3.2.4 Firing

Each facility has 1-2 kilns used for firing filters, which range in capacity from 80-240 filters (Table 5). The peak firing temperature ranges from 760-1100°C. Three of four facilities fire the filters slowly to ensure water in the mixture slowly evaporates (thus preventing cracking) until the burn-out starts combusting at about ~340-500°C. After that process is complete, the firing is resumed. The firing time ranges from 4.5 hours - 2 days. Three of four facilities use pyrometers and thermocouples to measure temperature in the kiln. No facility uses cones to measure the 'heatwork' – the effect of time and temperature on the ceramic material – as is recommended in the Best Practice manual.

Table 5: Firing Information at Four Ceramic Manufacturing Facilities Visited

	DR FilterPure	DR Atabey	Guatemala Ecofiltro	Haiti FilterPure
Number of kilns (for production)	1	1	2	1
Kiln capacity	84 (75 filters per firing)	250	240 each	72
Fuel source	Wood	Propane, converting to wood	Propane	Bagasse
Peak temperature	860°C	1100°C	760°C	830°C
Firing profile	Slowly to ~400°, pause during burn-out combustion, accelerated to 860°, held for 30 minutes.	Slowly to 600°, accelerated to 1100°.	Gradual to 380°, pause to 500°, resume to 750°, then stop.	Slowly to 340-360°, pause during burn-out combustion, resume and stop at 830°.
Firing time	4.5 hours	1.5-2.0 days	5-12+ hours	4 hours
Monitoring	Digital and analog pyrometer and 2 thermocouples	Digital pyrometer and one thermocouple	Pyrometer and 6 thermocouples	Digital pyrometer and thermocouple
Carbon core desired	Accepted	No black core	Desired	Accepted

3.2.5 Quality Control, Filtered Water Testing, and Documentation

All facilities carry out visual inspections of the filters to look for cracks, irregular rim shape or inconsistencies at multiple stages of the production process (Table 6). Three of the facilities also conduct auditory tests on all filters to ensure a ringing sound emits from the filter (suggesting the filter has been fired to temperature and does not have cracks) after firing. Rim pull tests – pulling the filter rim to identify filters with non-visible cracks or weak spots – are conducted on all filters at DR FilterPure and filters that fail the auditory test at Haiti FilterPure. A pressure test – submerging the filter base down to the rim in water and observing how long it takes for water to seep through the filter element to identify cracks or connected pores – is conducted at Haiti FilterPure on filters that fail the auditory test and pass the rim pull test and on filters that will be flow rate tested.

Only Guatemala Ecofiltro conducts flow rate testing on 100% of filters considered for sale (which is the recommended practice in the Best Practices manual); the remaining facilities test between 4-10% of filters. The minimum acceptable flow rate range is from 0.4-1.5 L/hr and the maximum is from 2.0-2.3 L/hr. Individual filters at Guatemala Ecofiltro that don't meet flow rate criteria are discarded. The protocols for what to do when flow rates don't meet criteria vary at the other three facilities.

Filtered water is tested for microbiological indicators internally (0-6%) and/or externally (0-0.4%) on between 0.1-6% of filters at the four facilities. The recommended practice is to test >1% and at least one per batch internally and to test 0.1% of filters considered for sale at an external testing location. At one of the facilities, influent water is not tested so a percent reduction or log reduction value cannot be calculated. DR FilterPure and Haiti FilterPure both incorrectly use an on-site most probable number (MPN) test tube method. The method is meant to be a 5-tube MPN method, but the facilities only use one tube per test, leading to a minimum detection limit of 20 MPN/100 mL. Instructions provided with the tubes do not indicate a recommended testing method or detection limit. DR FilterPure has recently implemented the Aquagenx Compartment Bag Test to supplement, and possibly replace, the current MPN test tube method.

The failure rates at the four facilities range from 6% to >40%. Process documentation is maintained at the DR FilterPure and Guatemala Ecofiltro facilities. Process documentation was being recorded at Haiti FilterPure electronically, but the database program was discontinued and no records are currently kept. The DR Atabey facility did not provide documentation information.

Table 6: Quality Control at Four Ceramic Manufacturing Facilities Visited

	DR FilterPure	DR Atabey	Guatemala Ecofiltro	Haiti FilterPure
Visual inspections	All filters (before trimming, before firing, after firing and before packaging)	All filters (before firing, after firing)	All filters (before trimming, after firing)	All filters (before trimming, before firing, after firing, before packaging)
Auditory inspections	All filters (after firing, before packaging)	All filters (after firing)	Occasionally	All filters (after firing)
Rim pull test	All filters (before packaging)	No	No	On filters that fail the auditory testing
Pressure test	Discontinued	No	No	On filters that fail auditory and pass rim pull and on filters that will be flow rate tested
Flow rate testing	12% (9/75)	4% (10/250), if any fail, the rest of the lot is tested	100%	6% (2/30)
Acceptable flow rate range	0.4-2.3 L/hr	1.5-2.0 L/hr	1-2 L/hr	0.7-2.2 L/hr
Microbiological testing	4% tested internally (3/75) 0.1% tested at lab (4/2400)	No internal testing 0.4% tested at lab (1/250)	No internal testing ~0.1% of filters produced tested at lab (5 filters per month)	6% tested internally (2/30) No external lab testing
Water tested	Influent and filtered water both internally and at lab	Filter taken to lab	Filter taken to lab, influent and filtered water tested	Filtered water only
Influent water	Stored, cistern or surface water	Lab	Lab	On site (drum) Not tested
Total failure rates	10-22%	6-8% pass after firing	>40%, variable	15-20%
Documentation	Extensive	Information not provided	Extensive	Database system discontinued, no documentation

3.2.6 Packaging

All four facilities package the filters with a plastic 5-gallon/20-Liter bucket for distribution in rural areas (Table 7). The advertised filter lifespan varies from 1-5 years. Each filter comes with cleaning instructions.

Table 7: Packaging at Four Ceramic Manufacturing Facilities Visited

	DR FilterPure	DR Atabey	Guatemala Ecofiltro	Haiti FilterPure
Receptacle	Food-grade plastic 20-L bucket (rural) Ceramic (urban)	Food-grade 20-L plastic buckets	20-L buckets (rural) Terra cotta/glazed (urban)	Food-grade 20-L bucket
Lifespan	5 years	1.5+ years	1 year	2 years
Cleaning instructions	Once a week brush inside and outside. Once every 3 months submerge in boiling or chlorinated water for 5 minutes.	When flow rate slows, wash with brush inside and outside to remove dirt.	Every 3 months clean with a new sponge and filtered water	Once a week brush inside and outside of filter, dip in chlorinated water for 5 minutes.

3.2.7 Health and Safety

All facilities are laid out appropriately for production flow (Table 8). Two of the three facilities where manufacturing was observed had sanitation facilities for employees. All three observed facilities had filters set up to treat drinking water for employees. Employees have access to personal protective equipment (PPE) – such as N95 facemasks, a uniform or plastic to cover clothing, and eye protection – at all three facilities. Only the Guatemala Ecofiltro facility cleans the facility floor with water, which is important to reduce the suspension of silica containing clay dust in the air. Dust suspension was noted as a concern at Haiti FilterPure facility while sieving clay. Smoke emissions from the kiln are also a health concern at the Haiti FilterPure facility.

Table 8: Health and Safety at Four Ceramic Manufacturing Facilities Visited

	DR FilterPure	DR Atabey	Guatemala Ecofiltro	Haiti FilterPure
Sanitation	Toilet on site, hand washing water available, and filter set up	Not observed	Bathroom (flush toilets, reliable supply), hand washing, and filtered drinking water	No sanitation facilities, hand washing water and filtered drinking water available.
Dust control	Equipment location separate from rest of facility, dry sweeping of floor		Facility cleaned with water, equipment location and model reduces exposure	None on sifter (model promotes dust suspension) dry sweeping of floor
Smoke control	Fine		Fine	Flames & smoke from kiln fill facility.
PPE available	N95 facemask, eye protection, work gloves, plastic sheets as aprons		N95 face masks, eye protection, gloves (silver application), uniforms	N95 facemasks, plastic sheets as aprons, eye protection. No heat gloves

3.3 Laboratory Testing of Filter Efficacy

Twenty-one filters were brought to Tufts laboratories for testing, including three filters with and without silver applied from DR FilterPure, DR Atabey and Guatemala Ecofiltro, and three filters without silver applied from Haiti FilterPure. Due to breakage in transport only 10 filters were able to be tested for *E. coli* LRV and silver elution (**Error! Reference source not found.**). Only Haiti FilterPure filtered water was tested for metals.

Table 9: Assessment of Four Facilities Visited and Certification Status

	DR FilterPure	DR Atabey	Guatemala Ecofiltro	Haiti FilterPure
Without silver	1	1	1	0
With silver	3	0	1	3

All of the Haiti FilterPure and Guatemala Ecofiltro filters tested met facility established flow rate criteria on the first flow rate test. All three of the with silver DR FilterPure filters with silver met facility flow rate criteria at first flow rate test, although the specially produced without silver filter had a slightly low (0.6 L/hr) flow rate. The DR Atabey filter had a high flow rate, at 3.5 L/hr on the first test. Flow rates increased across all filters tested upon the second flow rate test, which is consistent with other research[31].

The filter without silver from DR FilterPure and the filters with silver from DR FilterPure and Haiti FilterPure all met Best Practice manual guidelines for LRV of *E. coli* (>2 LRV in filters without silver or with silver embedded in the mixture) (Figure 5). The DR Atabey filters without silver and the Guatemala Ecofiltro filters with and without silver did not meet this guideline (indicated by the blue horizontal lines in the graphs).

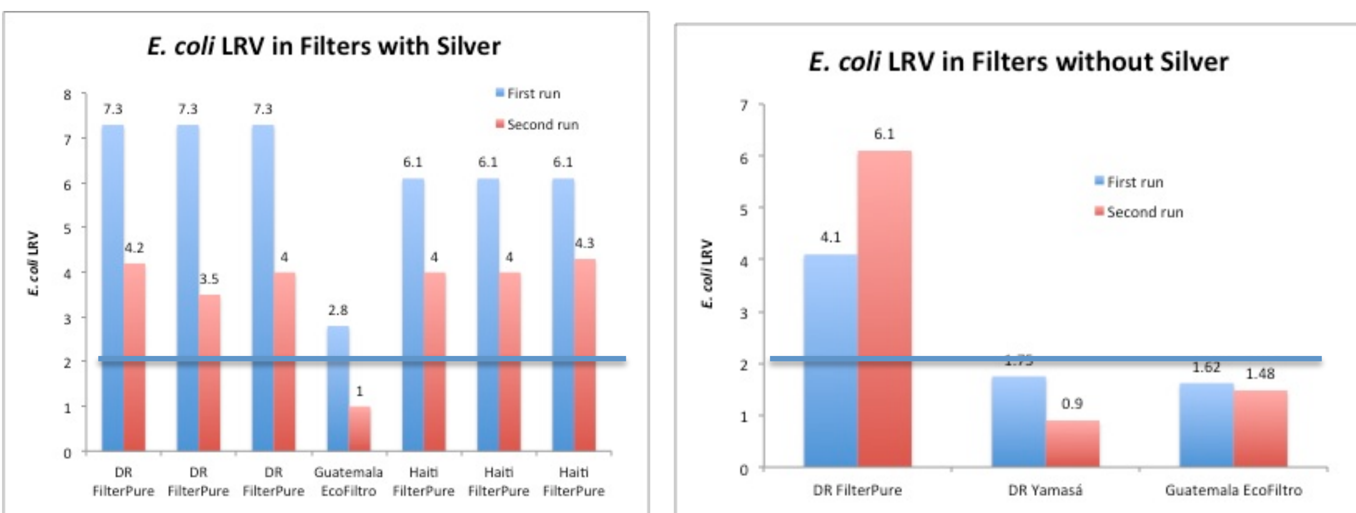

Figure 5: *E. coli* LRV Results from Four Facilities

All initial filtered water samples from filters with silver contained less than the WHO guideline value for silver in drinking water, except the initial filtered sample from one of the Haiti FilterPure filters. After three filter volumes were filtered (as per first use instructions to filter users), the silver concentration in filtered water was below WHO guideline value for all filters.

The collected barrel for filtered water containing all Haiti FilterPure effluent had 0.012 mg/L of silver and 0.056 mg/L of arsenic. This silver concentration is below the WHO guideline values, but the arsenic concentration is higher than WHO guideline values. Arsenic has been detected previously in filtered water from Ceramic Filters manufactured from other facilities, and attributed to arsenic in the raw clay material leaching into the water during filtration[30]. It is not, currently, known how to address this issue or how long the arsenic will continue to leach from the filter into the filtered water. Barium, cadmium, chromium, lead, mercury, and selenium were not detected in the filtered water.

As can be seen above, the DR FilterPure and Haiti FilterPure filters meet Best Practice manual recommendations for water treatment of >2 LRV reduction of *E. coli* in filtered water in filters with silver. Additionally, the DR FilterPure filter without silver also meets this recommendation. The low LRVs seen in both the Guatemala Ecofiltro filters with and without silver and DR Atabey filter without silver could in part be due to the relatively large burn-out material particle size (1/16th of an inch) used at these facilities. Prior research has found that large burn-out material particle size (which can lead to large, interconnected pore structures within the filter) is the manufacturing variable most associated with failing to meet *E. coli* LRV criteria[31]. Additionally, a recent manuscript found that – in Ceramic Filters manufactured at a different facility also with large burn-out particle size – *E. coli* reduction was not due to the actual filtration, but instead due to the contact time of the silver with the water in the storage container[32].

These laboratory results confirm the results seen in the facility assessment site visits.

Figure 6: Laboratory Test Set-up

3.4 Overall Summary and Certification Status

Quality assurance and quality control programs are designed to control input variables, evaluate consistency, and verify product quality. To obtain certification, facilities need to meet two critical criteria: 1) filters produced at the facility need to remove >2 LRV of *E. coli* without silver application (or with silver fired in); and, 2) production consistency needs to be demonstrated across time to ensure that subsequently produced filters (not only those tested) will meet this treatment standard. In addition, facilities must document production and promote a safe working environment for their employees.

Although all facilities work hard to produce filters, none of the facilities visited meet the criteria established for Certification (Figure 7). The required and recommended improvements identified during the facility site visits are presented on Page 27 and 28, and a summary paragraph on each facility is presented below.

Figure 7: Assessment of Four Facilities Visited and Certification Status

	DR FilterPure	DR Atabey	Guatemala Ecofiltro	Haiti FilterPure
Met >2 LRV criteria	Yes	No	No	Yes
Met production consistency criteria	No	No	No	No
Documents practices	Yes	Not in production, could not be evaluated	Yes	No
Meets health and safety requirements	Yes		Yes	No
Recommendation for Certification	Pending minor improvements	Not anticipated	Pending improvements	Pending improvements

Filters manufactured at DR FilterPure, both with and without silver included in the filter mixture, met LRV criteria. The filters are visually consistent with smooth surfaces and even coloring. DR FilterPure follows guidelines for materials sourcing, processing, and manufacturing consistency. Materials and methods used at the facility appear consistent; however, flow rate testing is not carried out on all filters and therefore production consistency cannot be evaluated. DR FilerPure carries out both laboratory and in-house testing on the recommended number of filters, but laboratory results indicate that influent water did not contain high concentrations of indicator bacteria, so treatment effectiveness is not evaluated regularly and one of the in-house test methods used does not detect <20 MPN/100mL of indicator bacteria. Auditory testing is the primary quality control test carried out. While other quality control evaluations have been implemented, rejection criteria are weak, for example, filters with visible cracks may be accepted if they pass in-house microbiological testing. Manufacturing at this facility is well documented. This facility meets most health and safety guidelines.

Filters manufactured at DR Atabey did not meet LRV criteria. The filters were visually inconsistent with imperfections such as different rim widths, hairline cracks, and deep grooves remaining from plastic mold release. The facility was not in production during the scheduled visit, therefore production could not be observed. The described manufacturing protocol does not follow guidelines for materials sourcing, processing, and manufacturing consistency. Flow rate testing is not carried out on all filters so production consistency cannot be evaluated. DR Atabey carries out laboratory testing on filters, but results were not provided. No information on health and safety precautions or documentation was provided.

Filters manufactured at Guatemala Ecofiltro did not meet LRV criteria. Although the filters have a visually consistent color and shape, the pore structure appears coarse. Flow rate test results at the facility result in a >30% rejection rate indicating that while Ecofiltro has a well defined manufacturing protocol, materials and/or methods are not well controlled during the production process. Reports on how and where filtered water samples were collected for testing at a local laboratory are contradictory, but results suggest filters have achieved a 2 LRV at local laboratories. In order to obtain certification, Ecofiltro needs to first modify materials and/or methods to produce a filter that meets LRV guidelines, before silver application, and then manufacture filters using the materials and methods consistently. Manufacturing is well documented and Ecofiltro provides a healthy working environment for their employees.

Filters manufactured at Haiti FilterPure meet LRV criteria, but only filters with silver fired-in were brought back and tested. The filters are visually consistent with smooth surfaces and even coloring. Haiti FilterPure meets most guidelines for materials processing and manufacturing consistency however, clay and sawdust can be of variable characteristics and the firing profile is not consistently achieved. While filters appear consistent, flow rate testing is not carried out on all filters and therefore production consistency cannot be evaluated. Laboratory testing is not carried out on the recommended number of filters, and although testing is carried out at the facility, the in-house test method cannot detect <20 MPN/100mL of indicator bacteria. The primary quality control evaluation is the auditory test. While other quality control tests are carried out, the rejection criteria are vague. Smoke and silica dust exposure are a health and safety concern at the facility. Haiti FilterPure has recently stopped documenting manufacturing, but their prior documentation system was thorough and requires only minor revisions to restart.

Overall, the results from the four facility site visits are sobering, but not unexpected. The Ceramic Manufacturing Working Group has been working on the quality control issue since 2008, and these results are much needed to better understand some of the challenges facilities face and how to move forward to establish quality controlled production. The facilities visited for these site assessments are passionate, intelligent, and dedicated to providing clean water to their constituents. It is anticipated that three of the four facilities will quickly work to modify their practices and meet Certification requirements.

DR FilterPure

Required improvements

- Flow rate test all filters to evaluate production consistency.
- Verify filtered water quality through laboratory efficacy testing when changing mixture ratio.
- When testing laboratory filter efficacy, use influent water containing indicator bacteria.
- Reject filters not pressed with a single charge of clay, uneven wall thickness, or visible cracks.

Recommended Improvements

- Carry out laboratory analysis of source water seasonally.
- Achieve even heat distribution during firing.
- Reinforce the press so mold retains alignment; confirm mold alignment.
- Modify standard in-house test protocol to obtain semi-quantitative results at <10 CFU/100mL.
- Discontinue rinsing filters with bleach before in-house efficacy testing.
- Clean facility with water to prevent silica dust suspension.

DR Atabey

Required Improvements

- Achieve >2 LRV of *E. coli*, with filters pre-silver application.
- Be in production during site visit, and have continuity in production.
- Stamp all filters with serial number and logo.
- Reject filters with visible cracks or inconsistent rim width that does not cover the receptacle rim.
- Apply a consistent amount of silver to each filter.
- Flow rate test all filters to evaluate production consistency.

Recommended Improvements

- Carry out laboratory analysis of source water seasonally.
- Carry out dry clay processing or demonstrate mixture ratio consistency.
- Consider reducing burn-out material particle size to increase efficacy.
- Align molds and check mold alignment regularly.
- Trim filters during the ‘leather hard’ stage.

Guatemala EcoFiltro

Required Improvements

- Filters must achieve >2LRV of indicator bacteria pre silver application.
- Verify filtered water quality through laboratory testing with change in ratio.
- Reject filter batches that have >20% flow rate test failure rate.
- Apply a consistent amount of silver to each filter.
- Carry out auditory testing on all filters.

Recommended Improvements

- Consider reducing burn-out material particle size.
- Monitor relative weight and volume of burn-out material.
- Control gradual and even filter drying.
- Increase mixture time to ensure even distribution of materials.
- Align molds and check mold alignment regularly.
- Achieve even heat distribution throughout the kiln and allow kiln to cool before opening doors.

Haiti FilterPure

Required Improvements

- Verify filtered water quality through laboratory testing with change in ratio.
- Resume documenting production; include materials source and processing.
- Repair or replace screen on sieve.
- Identify and reject filters with uneven wall thickness, rim deformation or cracks.
- Establish and implement rejection criteria for each quality control test.
- Document filter location in kiln, and achieve firing profile and even heat distribution.
- Flow rate test all filters and evaluate production consistency.
- Control smoke and clay dust exposure.
- Provide access to sanitation facilities.

Recommended Improvements

- Control burn-out material particle size.
- Carry out laboratory analysis of source water seasonally and investigate arsenic source.
- Evaluate clay for consistency.
- Monitor relative weight and volume of burn-out material.
- Identify and remove defective filters as early as possible from the production process.
- Decontaminate microbiological test samples before disposal.
- Discontinue rinsing filters with bleach before testing.
- Modify in-house test protocol to obtain semi-quantitative results at <10 CFU/100mL.
- Heat gloves should be available for employees during firing.

3.4.1 Next Steps and Follow-up

The first next step with this Certification Scheme will be to provide this report and the completed assessments to the participating facilities for their comments and responses. Then, the next meeting of the Ceramic Manufacturing Working Group will be held at a registered side-event from 8:30am-12:00pm at the University of North Carolina's Water and Health: Where Science Meets Policy conference on October 17th, 2014. All of these reports will be made available to side-event participants prior to the meeting. At the meeting, the primary topic of conversation will be: 1) discussion, potential for acceptance, and validation of the processes developed in this work; 2) whether to certify the facilities or not; and, 3) how to seek funding to continue this process and carry out this certification process at the >50 facilities worldwide. A particular concern is how to address facilities that have little outside support and operate intermittent production.

3.5 Survey of Filter Recipients in Haiti

3.5.1 Program and Household Selection

In March of 2014, organizations known to have a contact person and to have distributed, manufactured, and/or to have sold filters in Haiti were approached to determine if they would be interested in participating in the evaluation. The individuals contacted and spoken with in this process were: Martine Haentjens (Protos), Chris Rolling (Pure Water for the World), Noelle Thabault (Clean Water for Haiti), Fritz Pierre-Louis (the Sawyer Filter distributor in Haiti), Patrice Tallyrand (FilterPure Haiti), Jon Rose (Waves for Water), Roman Cipus (various), and Luc Hilhorst (the Lifestraw distributor in Haiti). Additionally, emails were sent to a representative at World Vision, who (according to Luc Hilhorst) had distributed the majority of the Lifestraw Filters.

Of the organizations contacted, PWW, CWH, FilterPure, and Sawyer Filter distributor Fritz Pierre-Louis expressed interest in being part of the study; no one associated with Lifestraw expressed interest. In coordination with the organizations, five filter distribution programs were evaluated (Table 10):

1. The PWW Biosand Filter program in Boudachita, where imported plastic-casing Hydraid Biosand Filters were installed at a subsidized price in a development program in a rural/semi-rural mountainous community on the road between Leogane and Jacmel. A community member is paid to be a Technician, and to answer questions and provide follow-up on the filters.
2. The CWH Biosand Filter program in the Artibonite Delta, where locally-manufactured concrete casing Biosand Filters were installed at a subsidized price in a development program. A community member is paid to be a Technician, and to answer questions and provide follow-up on the filters.
3. The CWH Ceramic Filter program in the mountains in Artibonite, where DR Atabey Ceramic Filters were distributed for free as part of an emergency response program to communities that were too remote to access with Biosand Filters. No follow-up was provided to these recipients.
4. The FilterPure Ceramic Filter program in Cayes de Jacmel, where Ceramic Filters were distributed at mobile health clinics in rural communities in collaboration with Association San Lucas d'Haiti (ASLDH). Ceramic Filters were distributed at no cost to patients who reported not treating their drinking water and expressed interest in the filter. Recipients received a 3-hour training on water, sanitation, and hygiene and filter operations and maintenance. No formal follow-up was provided.
5. Three communities between Leogane and Jacmel where Waves for Water and Fritz Pierre-Louis worked together with local organizations to distribute Sawyer filters on World Water Day of this year. Recipients in the GOALS program collaboration received a 3-hour training on the day of distribution. 'Coaches' in the community help families with their filter, but no formal follow-up program with families was established. Recipients in the Asosiyasyon Plante Mango Komin Leyogan program collaboration received one training on the day of distribution and no follow-up visits. Recipients in the Building Goodness Foundation program collaboration received one 45-minute training on the day of

distribution. Two local women were assigned to be program contacts, but were given no additional training to support families with filters.

Table 10: Household Survey Program Information

	PWW Biosand	CWH Biosand	CWH Ceramic	ASSLHA Ceramic	Various Sawyer
Program type	Installed by NGO at subsidized price, regular follow-up with local Technician	Installed by NGO at subsidized price, regular follow-up with local Technician	Distributed for free, no follow-up	Distributed for free, no follow-up	Distributed for free, variable follow-up
Program context	Development	Development	Emergency	Development	Development
Program area	Rural / Semi-Rural Mountains	Artibonite Delta / Rural	Rural Mountains	Semi-Rural	Coastal / Semi-rural Mountains
Approximate date of distribution	March - December 2013	October 2012 - November 2013	November 2011 - August 2013	March - April 2014	March 2014

We asked each of the organizations to provide a distribution list of households that received a filter (Table 11). In collaboration with the organizations, we selected a representative distribution region for sampling, and randomly selected 50 households within that region to survey. Criteria for region selection included: 1) more than 50 households had received filters in that region; and, 2) we could access and carry out 50 surveys in the allotted timeframe. PWW provided a complete electronic list of 330 Biosand Filter recipients in Haiti and the Duclo/Gran Savann region was selected for survey because of its proximity to Leogane (where the enumerators were initially based). CWH also provided their entire electronic distribution database. The Petit Dedune region was selected for Biosand Filter surveying because of the large number of filters installed in that region and because that region is representative of their current distribution strategy. The Fon Baptiste region was selected for Ceramic Filter survey because we could access that mountainous region in a 3-hour drive from the CWH office. Dr Erol of ASSLHA provided a list of Ceramic Filter recipients in Cayes de Jacmel, and Fritz Pierre-Louis provided a list of Sawyer Filter recipients in three communities along the road from Leogane to Jacmel. These regions were selected because distribution lists were available, and communities and households could be located.

Table 11: Household Surveys Completed

	PWW Biosand	CWH Biosand	CWH Ceramic	ASSLHA Ceramic	Various Sawyer	Summary
Number of names provided in geographic region	92	406	70	106	98	772
Number of names randomly chosen	50	50	53	50	50	253
Number (% of names chosen) of surveys completed	45 (90%)	44 (88%)	44 (83%)	44 (88%)	46 (92%)	223 (88%)

3.5.2 Survey Results

3.5.2.1 Household Demographics and Drinking Water Practices, Knowledge, and Beliefs

Some demographic indicators were similar across the five programs evaluated. The majority of respondents were female (68%-80%), the average respondent age was similar (36.7-42.2 years) across programs, and respondents reported fever (69%-91%) and headache (57%-71%) as the top health problems (Table 12). Please note that throughout the results table "n" is sample size.

There was significant variation between programs across other demographic indicators. Educational attainment varied, with 55%-91% of respondents reporting attending school across the programs, the mean years of schooling ranging from 5.1-10.3 years, and the reported percentage of female heads of household (HOH) and male HOH who can read ranging from 44%-76% and 68%-79%, respectively. Overall, less than half of respondents reported that a child under five years of age lived in the household, although this varied from 32%-68% by program. The majority of respondents (57%) reported being Protestant, with a range of 41%-82% by program. Indicators of high socio-economic status (SES) also varied, with 23%-100% of households having a concrete floor and 0%-77% of households having wired electricity.

Respondents in the CWH ceramic program had the lowest educational attainment and socio-economic indicators and the highest percentage of households with children <5. Respondents in the ASSLHA Ceramic and Sawyer Filter programs had the highest educational attainment and socio-economic indicators.

Table 12: Household Demographic Descriptive Statistics

	PWW Biosand	CWH Biosand	CWH Ceramic	ASSLHA Ceramic	Various Sawyer	Summary
% (n) Female respondents	72% (45)	87% (44)	68% (44)	80% (44)	78% (46)	77% (223)
Mean (SD) respondent age, n=	42.2 (18.0) n=45	38.4 (13.1) n=44	36.7 (13.3) n=44	37.8 (16.5) n=44	41.6 (14.6) n=46	39.3 (15.2), n=223
% (n) Respondents attended school	60% (45)	68% (44)	55% (44)	91% (44)	70% (46)	69% (223)
Mean (SD) if Yes school, respondent years of schooling, n=	7.6 (3.4) n=28	7.2 (3.2) n=30	5.1 (2.8) n=24	10.3 (3.5) n=40	7.0 (3.7), n=32	7.7 (3.7) n=154
% (n) Female HOH can read	61% (41)	59% (41)	44% (43)	76% (42)	55% (45)	59% (211)
% (n) Male HOH can read	71% (41)	70% (39)	68% (41)	79% (39)	70% (40)	71% (199)
% (n) HH has at least one child <5	40% (45)	48% (44)	68% (44)	32% (44)	37% (46)	45% (223)
% (n) Catholic religion	11% (45)	36% (44)	30% (44)	46% (44)	44% (46)	33% (223)
% (n) Protestant religion	82% (45)	41% (44)	68% (44)	50% (44)	44% (46)	57% (223)
% (n) Practice voodoo	2% (45)	25% (44)	2% (42)	7% (44)	24% (46)	12% (221)
% (n) House has concrete floor	53% (45)	23% (44)	59% (44)	100% (44)	72% (46)	61% (223)
% (n) Has wired electricity	0% (44)	77% (44)	0% (44)	51% (43)	2% (46)	26% (221)
% (n) Top reported health problem	Fever: 69% n=45	Fever; 77% n=44	Fever: 82% n=44	Fever; 78% n=44	Fever; 91% n=46	Fever; 80% n=223
% (n) Second most common reported health problem	Headache: 69% n=45	Headache: 71% n=44	Headache: 59% n=44	Headache: 59% n=44	Headache: 57% n=46	Headache: 63% n=223

Drinking water sources varied across the programs evaluated, with the two mountainous areas (PWW Biosand and CWH Ceramic) reporting use of protected and unprotected springs, the Artibonite Delta (CWH Biosand) area reporting use of surface water and canal soures, and the relatively more educated and higher SES programs (ASSLHA Ceramic and Sawyer) reporting use of improved water sources (Table 13). The average amount of time per water collection trip was 15 minutes or less in all programs except the CWH Ceramic program.

Nearly all respondents (95%) reported knowing that drinking water can make you sick, and most respondents felt their water was safe to drink (86%). The most commonly reported reason for thinking drinking water was safe across all programs was that it was 'treated' (95%), and the most commonly reported reason for not thinking drinking water was safe was that it was 'not treated' (81%). A large majority of respondents reported receiving Aquatabs since the beginning of the cholera epidemic (82%). Overall, 95% of households had a 5-gallon water storage container, and enumerators observed that 56% had access to a latrine, 11% had a handwashing station, and 5% had soap at the handwashing station. These hygiene indicators were highest in the ASSLHA Ceramic and Sawyer Filter programs, and lowest in the CWH Ceramic program.

Table 13: Drinking Water and Sanitation Practices, and Water Safety Beliefs

	PWW Biosand	CWH Biosand	CWH Ceramic	ASSLHA Ceramic	Various Sawyer	Summary
% (n) Most common reported water source	Protected spring 53% (45)	Surface water 50% (44)	Unprotected spring 91% (44)	Kiosk or tap not at house 57% (44)	Kiosk or tap not at house 37% (46)	Unprotected spring 29% (223)
% (n) Second most common reported water source	Unprotected spring 29% (45)	Canal 27% (44)	Protected spring 7% (44)	Tap at house 30% (44)	Protected well 28% (46)	Kiosk or tap not at house 22% (223)
Median (IQR) minutes to reach water source, collect water, and return (n=)	15 (38.1), n=44	7.3 (26.5), n=44	60 (30), n=44	7.5 (13.4), n=36	7.5 (27.0), n=46	15 (35), n=214
% (n) Respondents thinks that drinking water can make you sick	100% (45)	86% (44)	89% (44)	98% (44)	100% (46)	95% (223)
% (n) Respondents thinks their water is safe to drink	96% (45)	81% (44)	70% (43)	89% (44)	91% (46)	86% (222)
% (n) Top reported reasons for thinking water is safe to drink	Treated 96% (45)	Treated 96% (44)	Treated 89% (44)	Treated 98% (44)	Treated 98% (46)	Treated 95% (223)
% (n) Top reported reasons for thinking water is not safe to drink	Not treated 76% (45)	Not treated 82% (44)	Not treated 75% (44)	Not treated 89% (44)	Not treated 85% (46)	Not treated 81% (223)
% (n) Reported receiving Aquatabs since cholera began	87% (45)	71% (44)	84% (44)	64% (44)	76% (46)	82% (223)
% (n) Report receiving Jif since cholera began	7% (45)	34% (44)	11% (44)	5% (44)	7% (46)	13% (223)
% (n) Has 5-gallon water storage container	100% (45)	98% (44)	88% (44)	89% (44)	98% (46)	95% (219)
% (n) Latrine present	71% (45)	41% (44)	23% (44)	79% (43)	67% (46)	56% (222)
% (n) Place to wash hands	16% (45)	7% (44)	5% (44)	21% (44)	7% (46)	11% (223)
% (n) Soap present	7% (43)	2% (44)	0% (44)	14% (44)	2% (46)	5% (221)

3.5.2.2 Filter Usage, Training, Operation, and Maintenance

Of the 223 families surveyed – which were all on organization distribution lists – 92% reported they had actually received a filter (Table 14). The lower percentages reported having received filters were in the Ceramic programs (82%-87%) and the highest percentages were in the Biosand programs (98%-100%). The average reported amount paid for filters was 203.4 Gourdes (4.47 USD), although this varied substantially by program. The majority of the Biosand recipients, more than half of the CWH Ceramic recipients, and very few to none of the ASSLHA Ceramic and Sawyer program recipients reported paying for filters.

Overall, 87% and 77% of recipients reported ever using their filters and using their filters in the last week, respectively. The highest rates of reported use were in the Biosand programs (96%-100%), with the lowest rates in the CWH Ceramic program (39% in last week). About three-quarters of ASSLHA Ceramic and Sawyer Filter users reported use. The most common use of filtered water was for drinking (84%), followed by for cooking (37%) and for bathing/other (17%). A higher percentage of Biosand Filter respondents reported using their filtered water for uses other than drinking water as compared with Ceramic and Sawyer Filter recipients. Across all programs, participants reported that the main reason for filter use was 'to make water clean'. Across all programs, over three-quarters of respondents reported that household members sometimes drink untreated water (average 76%, range 58%-88%). The top reported reason for drinking untreated water varied by filter type; Biosand and Sawyer Filter recipients said they drank untreated water when 'outside of home' and Ceramic Filter recipients stated that they drank untreated water because they had 'no filtered water'.

Table 14: General Filter Usage Information

	PWW Biosand	CWH Biosand	CWH Ceramic	ASSLHA Ceramic	Various Sawyer	Summary
% (n) Reported ever receiving a filter	100% (45)	98% (44)	87% (44)	82% (44)	96% (46)	92% (223)
Mean (SD) Reported Gourdes paid for filter, n=	195.2 (19.6) n=44	201.2 (7.7) n=42	220.0 (61.2) n=25	225 (35.4) n=2	-- n=0	203.4 (32.9) n=113
% (n) Reported have ever used filter	100% (45)	96% (44)	80% (44)	77% (44)	83% (46)	87% (223)
% (n) Reported using filter in last week	100% (45)	96% (44)	39% (44)	73% (44)	76% (46)	77% (223)
% (n) Reported uses for filtered water						
Drinking	100% (45)	96% (44)	66% (44)	77% (44)	80% (46)	84% (223)
Cooking	33% (45)	82% (44)	21% (44)	16% (44)	33% (46)	37% (223)
Washing fruits/vegetables	9% (45)	0% (44)	0% (44)	7% (44)	0% (46)	3% (223)
Bathing/Other	15% (45)	30% (44)	5% (44)	16% (44)	17% (46)	17% (223)
% (n) Top reported reasons for using the filter	To make water clean; 80% (45)	To make water clean 84% (44)	To make water clean 55% (44)	To make water clean 61% (44)	To make water clean 72% (46)	To make water clean 70% (223)
% (n) HH members report sometimes drinking untreated water	76% (45)	58% (43)	75% (39)	88% (36)	80% (44)	76% (157)
% (n) Top reasons for when/where they drink untreated water	Outside of home 67% (34)	Outside of home 55% (25)	No filtered water 55% (33)	No filtered water 59% (30)	Outside of home 57% (35)	Outside of home 82% (157)

Overall, 89% of respondents reported receiving some training on the filter (Table 15). In all programs except CWH Biosand, which carries out follow-up household visits, the majority of trainings reported were community meetings. The percent of respondents who could name the person they would contact if they had a question about their filter varied dramatically, from 18%-89%. The lowest rate (18%) was seen in the CWH Biosand program, and the highest rate (89%) in the PWW Biosand program. Very few problems with filters were reported, except in the CWH Ceramic program, where 43% (19/44) reported their filter was broken; with 15 of the 19 breakages were of the Ceramic Filter element itself. One respondent mentioned that their Sawyer Filter leaked. A small minority (8%) knew where they could buy replacement parts for their filter.

Table 15: Self-reported Filter Training, Operation, and Maintenance Information

	PWW Biosand	**CWH Biosand**	**CWH Ceramic**	**ASSLHA Ceramic**	**Various Sawyer**	**Summary**
% (n) Reported someone in household received filter use training	100% (45)	98% (44)	77% (44)	80% (44)	91% (46)	89% (223)
% (n) Most common type of training received on filter use	Community meeting 87% (45)	Household visit 68% (44)	Community meeting 50% (44)	Community meeting 73% (44)	Community meeting 80% (46)	Community meeting 60% (223)
% (n) Could name who to contact if they had questions about the filter	89% (45)	18% (44)	30% (44)	45% (44)	68% (46)	47% (223)
% (n) Reported knowing where to buy replacement parts	24% (45)	2% (44)	2% (44)	11% (44)	0% (46)	8% (223)

Ceramic Filter respondents reported using a brush (50%) or cloth (23%) to clean their filter, although 60% of respondents reported using this brush/cloth for other household purposes (Table 16). Only half (51%) of respondents used clean water to clean the filter. Overall, 65% of households were able to show the installed Ceramic Filters. Upon observation, 43% had a lid in good condition, 58% had the filter on a raised surface, 17% had cracked or chipped filter rims, and 44% had water in their filter membrane or storage container. These numbers raise concerns about the operations and maintenance of Ceramic Filters. The ASSLHA Ceramic Filters (distributed more recently) had better operations and maintenance indicators than the CWH Ceramic.

Table 16: Self-reported Operations and Maintenance Information, and Observations: Ceramic Filter

	CWH Ceramic	ASSLHA Ceramic	Summary
% (n) Reported tool used to clean filter membrane			
Cloth	32% (44)	16% (44)	23% (88)
Brush	39% (44)	61% (44)	50% (88)
% (n) Reported using the cloth/brush for other uses	52% (44)	68% (44)	60% (88)
% (n) Reported using treated water to clean filter membrane	39% (44)	64% (44)	51% (88)
% (n) Respondent showed the filter to enumerator	48% (44)	82% (44)	65% (88)
% (n) Filter has lid in good condition with good fit	14% (44)	73% (44)	43% (88)
% (n) Filter is located on raised surface (off of the floor)	41% (44)	75% (44)	58% (88)
% (n) Filter rim is cracked or chipped	9% (44)	25% (44)	17% (44)
% (n) Filter membrane or storage container has water	28% (44)	61% (44)	44% (88)

Figure 8: (clockwise from top left) DR Atabey Ceramic Filter, a Haiti FilterPure Ceramic Filter, a Broken Ceramic Filter, a DR Atabey Filter Unit

Reported cleaning methods for Biosand Filters varied, with 80% using the 'swirl and scoop' method, 29% washing the outlet, 25% washing the filter exterior, 42% washing the lid, and 63% washing the diffuser plate (Table 17). Overall, 99% of respondents were able to show enumerators their filter. The filters were in generally good condition, with 97% with a lid with good fit, 87% with a diffuser plate in good condition, 74% with level sand, 58% with correct standing water depth, and 91% having a dedicated safe storage container with lid and tap. Across all indicators, the more recent PWW Biosand program performed slightly better than the longer running CWH Biosand program. Lastly, 40% of respondents reported further treating their filtered water with chlorine before drinking.

Table 17: Self-reported Operations and Maintenance Information, and Observations: Biosand Filter

	PWW Biosand	CWH Biosand	Summary
% (n) Reported methods of filter cleaning			
Wash diffuser plate	73% (45)	52% (44)	63% (89)
Wash lid	58% (45)	25% (44)	42% (89)
Wash filter exterior	27% (45)	23% (44)	25% (89)
Wash outlet	33% (45)	25% (44)	29% (89)
"Swirl and scoop" method to clean sand layer	71% (45)	89% (44)	80% (89)
% (n) Respondents showed the filter to enumerator	100% (45)	98% (44)	99% (89)
% (n) Filter has lid in good condition with good fit	100% (45)	93% (44)	97% (89)
% (n) Filter has diffuser plate in good condition with no cracks	96% (45)	77% (44)	87% (89)
% (n) Top layer of sand in filter is level	87% (45)	61% (44)	74% (89)
% (n) Standing water depth between 3-7 cm	64% (45)	52% (44)	58% (89)
% (n) User has a dedicated safe storage container with lid and tap	100% (45)	82% (44)	91% (89)
% (n) Report further treating filtered water	33% (45)	46% (44)	40% (89)

Figure 9: A CWH Biosand Filer, a PWW Biosand Filter, Measuring Water Depth

Sawyer recommends regular backwashing with a provided syringe to maintain the Sawyer Filter. Overall, 72% of respondents reported using the syringe, 70% were able to show enumerators the syringe, and 37% reported using treated water to backflush the filter (Table 18). Overall, 85% of respondents were able to show the filter, with about two-thirds to three-quarters of respondents having good installation, including a lid on the top bucket (65%), the filter raised off the floor (76%), the filter suspended from the top bucket (65%), water in the top bucket (72%), and a dedicated safe storage container (65%). It is of note that during the surveys, enumerators and staff noted that many filters looked brand-new and recently installed, and that Sawyer Filter program staff were seen with several worn or broken Sawyer Filters on the day of the survey. In particular, one household was randomly selected to be surveyed for both the PWW Biosand program and the Sawyer Filter program. At the first visit (for the PWW Biosand evaluation), only the PWW Biosand Filter was installed. At the second visit (for the Sawyer Filter evaluation) a Sawyer Filter was installed on top of the Biosand Filter.

Table 18: Self-reported Operations and Maintenance Information, and Observations: Sawyer Filter

	Various Sawyer
% (n) Most commonly reported tool used to backflush filter	Syringe 72% (46)
% (n) Showed syringe	70% (46)
% (n) Reported using treated water (boiled, chlorinated, filtered) to backflush filter	37% (46)
% (n) Respondent showed the filter to enumerator	85% (46)
% (n) Top filter assembly bucket has lid in good condition with good fit	65% (46)
% (n) Filter assembly is located on raised surface (off of the floor)	76% (46)
% (n) Filter is suspended or hooked on side of the bucket	65% (46)
% (n) Top filter assembly bucket has water in it	72% (46)
% (n) User has dedicated safe storage container with lid and tap	65% (46)

Figure 10: An Uninstalled and Newly Installed Sawyer Filter

3.5.3 Water Quality Testing Results

Greater than 90% of households in all programs had stored household drinking water at the time of the unannounced survey visit (Table 19). Between 52% (CWH Ceramic) and 89% (PWW and CWH Biosand) reported that that household drinking water was in some way treated, with 27% (CWH Ceramic) to 78%-80% (PWW and CWH Biosand) of respondents reporting the stored household water was treated with the filter of interest (the filter given to them by the program being investigated). Other HWT options reportedly used for water treatment were predominantly Aquatabs and other chlorine-based options. Overall, 20%-57% of households were able to provide untreated-treated water pairs, and 16%-57% of households were able to provide untreated-direct from filter-treated water) sample trios.

Figure 11: Collecting a Water Sample

Table 19: Drinking Water Samples Provided

	PWW Biosand	CWH Biosand	CWH Ceramic	ASSLHA Ceramic	Various Sawyer	Summary
% (n) Provided stored drinking water sample	93% (45)	96% (44)	91% (44)	93% (44)	96% (46)	94% (223)
% (n) Drinking water sample was reportedly treated	89% (45)	89% (44)	52% (44)	66% (44)	72% (46)	74% (223)
% (n) Drinking water sample was reportedly treated with filter of interest	78% (45)	80% (44)	27% (44)	50% (44)	57% (46)	58% (223)
% (n) Provided two water samples: untreated and treated with filter of interest	56% (45)	57% (44)	20% (44)	48% (44)	52% (46)	47% (223)
% (n) Provided three water samples: untreated, stored treated, and direct from filter outlet	56% (45)	57% (44)	16% (44)	39% (44)	50% (46)	43% (223)

In four of the five programs, the median turbidity of untreated water was low (0.32-1.21 NTU) (Table 20). Given the low turbidity of the water, little to no reduction of turbidity was seen in treated water samples. In the CWH Biosand program however, which used canal and surface water sources primarily, source water turbidity was quite high (36.80 NTU median). Turbidity was drastically reduced to a median of 0.31 NTU in treated water samples.

E. coli concentrations in untreated water samples varied dramatically, with low-risk geometric mean *E. coli* concentrations in programs using predominantly kiosk, tap, and protected well source waters (ASSLHA Ceramic and Various Sawyer), medium-risk *E. coli* concentrations in programs using protected and unprotected spring source water (PWW Biosand and CWH Ceramic), and high risk geometric mean *E. coli* concentrations in programs using predominantly surface water sources (CWH Biosand). Across all programs the direct-from-filter samples were of higher microbiological quality than the stored household water samples obtained from the cup, indicating recontamination during storage, which is well-documented in the literature and a limitation of filtration-only programs[11].

Overall, 0% (CWH Ceramic) to 48% (ASSLHA Ceramic) of households with untreated-treated water pairs were able to improve the quality of their drinking water using the filter of interest from contaminated (≥1 to <1 CFU/100 mL of E. coli). As can be seen in Figure 12, the reasons for these relative low rates of water quality improvements vary: 1) while all but one untreated water sample in the PWW and CWH Biosand Filter projects were contaminated, the filter did not effectively treat water in all cases to <1 CFU/100 mL, which is consistent with other research that Biosand filters reduce most, but not all, of the bacteria; 2) while all untreated water samples were contaminated in the CWH Ceramic Filter project, this filter was also ineffective at reducing treated water to <10 CFU/100 mL, which is inconsistent with the literature[22-24], and an indication that there are manufacturing concerns with these Ceramic Filters; 3) while the ASSLHA Ceramic Filter was very effective at reducing *E. coli* to <1 CFU/100 mL in treated water samples, the filters were installed in an area where 33% of source water samples had <1 *E. coli* before treatment, limiting the potential improvement; and, 4) while Sawyer Filters did improve the microbiological quality of treated water, it was incomplete improvement, which is consistent with other research showing that membrane fouling in the Sawyer Filter over time can decrease microbiological effectiveness.

Effective use is the estimate of the percent of the targeted population that is using the filter to improve their water quality. When the percentage of households who improved the microbiological quality of their drinking water is multiplied by the percentage of households who reported using the filter, effective use rates of 0%-34% are seen in this study. The highest effective use rates are seen in programs that provide a treatment option that effectively improves water quality to a population with contaminated drinking water who is willing and able to use that treatment option. Thus, in this study, there was no one filter installed that met all the criteria for having effective use – as there was low contaminated drinking water in the ASSLHA Ceramic (which had the highest improvement percentages) and Sawyer Filters, low full microbiological improvement in CWH Ceramic, CWH Biosand, and PWW Biosand, and lack of a quality product in CWH Ceramic.

These results do not mean that there is not microbiological improvement in these filters, but do show that the filters, in general, do not provide water that meets the Haitian Government standard of <1 *E. coli*/100 mL of drinking water.

If these results are evaluated against the metric of <10 *E. coli*/100 mL (which is not currently supported by the Haitian Government, but could be advocated for), the effective use numbers change. The CWH Biosand Filter program, which effectively reduced the majority of *E. coli* in a contaminated environment, now has an effective use rate of 45% - meaning almost half of the recipients are improving the quality of their stored household drinking water to meet low-risk international standards. The PWW Biosand Filter program effective use remains the same, the CWH Ceramic Filter program effective use increases slightly because – even though that filter was of poor quality it still sometimes efficaciously treated water to <10 CFU *E. coli*/100 mL. The ASSLHA Ceramic and Sawyer Filter distributions drop in effective use because of the low levels of contamination in the source water of the recipients.

Table 20: Water Quality Test Data

	PWW Biosand	CWH Biosand	CWH Ceramic	ASSLHA Ceramic	Various Sawyer	Summary
Turbidity (n) - NTU						
Median (IQR) turbidity of untreated water samples (NTU)	0.49 (0.84) n=11	36.80 (48.49) n=10	1.21 (3.16) n=13	1.09 (4.54) n=16	0.32 (0.45) n=27	0.67 (1.99) n=77
Median (IQR)) turbidity of treated water samples (NTU)	0.10 (0.65) n=11	0.31 (0.57) n=10	1.73 (6.61) n=13	1.00 (1.41) n=16	0.28 (0.60) n=27	0.39 (1.18) n=77
E.coli (n) – CFU/100 mL						
Geometric mean untreated water (min, max)	29.3 (5-485) n=25	485 (0-4250) n=25	78.5 (10-755) n=9	3.92 (0-250) n=21	8.61 (0-4000) n=24	n/a
Geometric mean direct-from-filter water (min, max)	0.55 (0-40) n=25	0.53 (0-427) n=25	20.5 (2-260) n=7	0 (0-0) n=17	0.35 (0-36) n=23	n/a
Geometric mean treated water (min, max)	1.14 (0-110) n=25	4.12 (0-4000) n=25	16.4 (2-980) n=9	0.33 (0-400) n=21	0.65 (0-400) n=24	n/a
% improved from ≥ 1 to <1	44% n=25	20% n=25	0% n=9	48% n=21	46% n=24	n/a
Reported use with filter of interest	78% n=45	80% n=44	27% n=44	50% n=44	57% n=46	n/a
Effective use (% with reported treatment x % improved) [using <1 CFU/100 mL as the breakpoint]	34%	16%	0%	24%	26%	n/a
% improved from ≥ 10 to <10	44% n=25	56% n=25	33% n=9	29% n=21	29% n=24	n/a
Effective use (% with reported treatment x % improved) [using <10 CFU/100 mL as the breakpoint]	34%	45%	9%	15%	17%	n/a

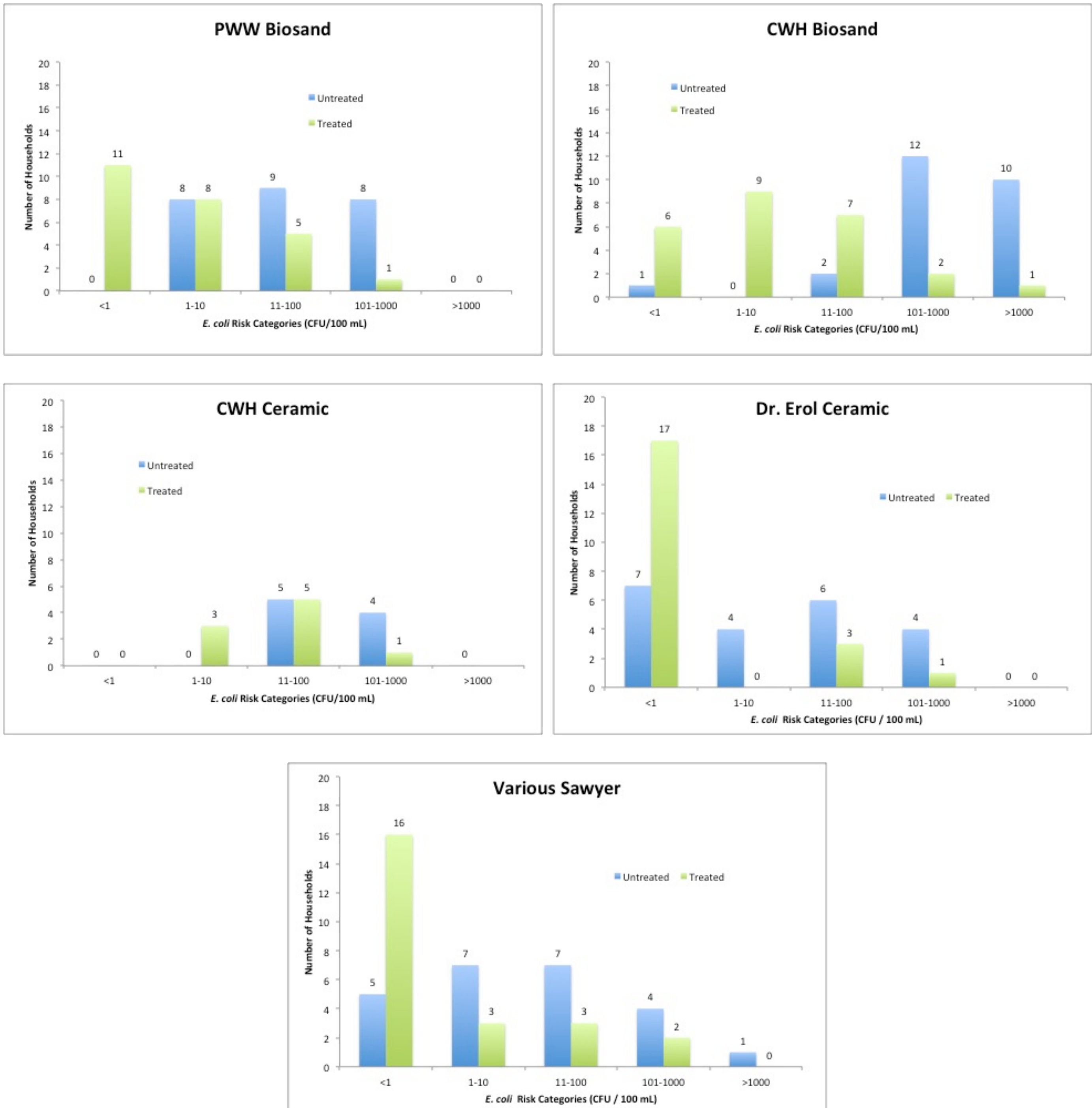

Figure 12: Microbiological Results from Five Programs

4 Discussion

This multi-investigation study allowed us to obtain significant information on the efficacy and effectiveness of filters distributed in response to cholera in Haiti. Our results both confirm and expand upon previous results and highlight the difficulty in ensuring HWTS programs reach their goal of improving the microbiological quality of household stored drinking water and reduce the risk of diarrheal disease. While filters can be an effective option to improve the microbiological quality of household stored drinking water in Haiti, the results presented herein are sobering and highlight the factors necessary to reach this goal, including: 1) quality controlled (local) manufacturing; and, 2) distribution of filters to those with contaminated source water with sufficient training and materials for recipients to use the filters correctly and consistently to improve the quality of their household drinking water.

Concerns about poor quality control in decentralized Ceramic Filter manufacturing facilities were first raised in 2008, and over the past six years the Ceramic Filter community has come together to develop guidelines which have been presented in the Best Practices manual and to encourage the development of a Certification Scheme[30]. The four facility visits detailed herein are a trial of a proposed Certification Scheme, and the results from these facility visits confirm prior work that found manufacturing variation can impact filter efficacy.

One of the four facilities visited (DR FilterPure) was the closest to demonstrating that they consistently manufacture quality filters as: 1) their filters achieved microbiological efficacy standards (>2 LRV of spiked *E. coli* in the laboratory); and, 2) their materials and processes appeared consistent during the site visit. Additionally, the DR FilterPure facility documents production and promotes a safe working environment for their employees. Small changes to verify production consistency and improve quality control are needed before the DR FilterPure facility can be recommended for Certification.

Filters from the Haiti FilterPure facility also met microbiological efficacy standards, and the facility also needs to demonstrate consistency of production. Additionally, they need to resume manufacturing documentation and implement some health and safety improvements. It is anticipated that the Haiti FilterPure facility will work on the process improvements that would allow for Certification.

The DR Atabey and Guatemala Ecofiltro facilities met neither criterion for Certification. It is recommended that Guatemala Ecofiltro work to determine the cause(s) – be it large size sawdust used in processing, kiln management, or another production issue – for the high rejection rate of filters and the low microbiological efficacy; it is anticipated once these causes are identified, Certification can proceed.

The results presented herein highlight the need to have a Certification Scheme for Ceramic Manufacturing Facilities to ensure quality control of locally-manufactured products. These results herein will be: 1) distributed to the participating facilities for review and comment; and, 2) presented and discussed at the CMWG meeting at

UNC-W&H meeting in October to determine how to move forward with a Certification Scheme process. A grant has been submitted for research on Ceramic Filters that includes funding for 15 facility visits – it is hoped this work can be continued if that grant is awarded.

Our survey of 223 households who were documented to have recieved a Ceramic, Biosand, or Sawyer Filter in Haiti also provided sobering results. The five programs evaluated varied from emergency distributions with no follow-up to longer-term development programs with consistent training, follow-up, and oversight. Source waters used by filter recipients varied from highly clean kiosk and tap water to very contaminated surface and canal water sources. The vast majority of respondents reported knowing that water can make you sick, and consistent with other research[17], the main reason water was considered safe was that it has been 'treated'. The vast majority of households used a 5-gallon storage container. Latrine presence was moderate (56%), and handwashing stations and soap presence was very low (5%-11%).

The majority of households in all but one of the programs reported using the filter in the last week, but concerningly, 82% of respondents reported drinking unfiltered water when out of the home (for Biosand and Sawyer Filters) or when there was no filtered water (for Ceramic Filters). Overall, 58% of households reported they had filtered water with the filter that they had received at the time of the unannounced visit (range 27%-80%). Effective use (the percentage of the target population that improved their water from contaminated (≥1 CFU *E*. coli/100 mL) to uncontaminated <1 CFU *E. coli*/100 mLwith the filter) was low to medium across all programs – from 0% to 34%. Using a breakpoint of <10 *E. coli*/100 mL for the effective use metric more accurately reflects the risk reduction in programs with untreated water with high levels of *E. coli* contamination, with effective use percentages of 9-45%.

However, the <10 *E. coli*/100 mL metric is currently not supported by the Haitian Government, where the drinking water standard is <1 *E. coli*/100 mL. Given the importance of clean water, it is recommended that Biosand and Sawyer Filter programs consider recommending post-chlorination of filtered water to ensure adequate disinfection during water storage. Clean Water for Haiti, in fact, already recommends this. For well-manufactured Ceramic Filters (such as DR FilterPure), this is not recommended due to the integral design of the safe storage container into the filter.

Program sustainability is also questionable, as only 8% of the respondents knew where to obtain replacement parts and only 47% knew the name of a person to talk to if they had questions about the filter. Breakage was noted in the Ceramic Filter program, particularly in the program that distributed filters up to 2 years earlier, which is consistent with previous work that Ceramic Filter use is association with time since distribution.

There are limitations to this survey, including that: 1) programs without distribution lists were not included, which most likely biases the results to have higher use and effective use rates; 2) there were questions about when the Sawyer Filter installations occurred; and, 3) it is not able to compare the programs due to differences in the recipient populations, including education and socio-economic status. Please also note that because this was program evaluation of programs with distribution lists, the denominator used in analysis was, for the most part, all surveyed households. Further analysis of the survey data is planned, and a manuscript on this data will be prepared, cleared through CDC, and submitted.

While it is not possible to directly compare the programs, some themes that have been noted in previous literature also appear in this study. Well-manufactured Ceramic Filters were more effective at treating water to <1 *E. coli*/100 mL, but were more likely to break. Recipients were also more likely to report they drank untreated water because there was no filtered water, which is likely attributable to the relatively lower flow rate of Ceramic Filters. Biosand Filters were less effective at treating water to <1 *E. coli*/100 mL, and treated water was more likely to be used for uses in addition to drinking water, which is likely attributable to the higher flow rate.

In order to have a successful HWTS filter program, each step needs to be well-implemented, including: 1) production or importation and subsequent distribution of a filter that successfully removes *E. coli* from the source waters to be treated; and, 2) distribution of that filter to households that have contaminated water sources and are sufficiently trained to use the filter to improve the quality of their household stored water. To our knowledge, this is the first study that investigated that entire chain – from production to household use. Our results are sobering, with all four Ceramic Filter manufacturing facilities not (yet) achieving recommended LRVs of *E. coli* and/or not documenting consistent production practices and household use lower than anticipated in many programs. Our results also document the first known instance of lower quality Ceramic Filters (from DR Atabey) leading to poor reduction of *E. coli* at the household level in users of that filter.

However, the results are also promising, as it is anticipated that three of the four production facilities could achieve Certification with achievable improvements, and there was high levels of use and medium levels of effective use in programs that provided filters to households with training, education, and follow-up. This result is very similar to previous results showing that HWTS can, if implemented in certain ways, be a mechanism to reduce the risk of diarrheal disease in users.

5 Conclusions

The investigations completed within this work and presented herein highlight the difficulties, and successes, in using household filters to improve the microbiological quality of household stored water and reduce the risk of diarrheal disease and cholera transmission in Haiti. While there are successes with programs that provide a high-quality product to users with contaminated water who are trained and supported in using that filter (such as the CWH and PWW Biosand Filter programs), the overall results presented herein are consistent with previous research of other HWTS options in Haiti: successful HWTS programs depend on community support and structure, and this is unchanged even when distributing durable products such as filters. It is unrealistic to distribute a durable product and assume that product is being used to improve water quality in the absence of an ongoing support structure. The challenge will be in supporting the scaling-up of these community-based projects to reach a scale to reduce the risk of diarrheal disease and cholera transmission in Haiti.

6 Budget

The budget for the projects detailed above was 35,000 USD, including 10,000 for salary, 14,500 for site visits to Ceramic Filter facilities, 4,000 for water testing equipment, 5,000 for survey costs, and 1,500 for supplies and expenses. This budget was fully expended.

Additionally, approximately 8,000 USD of laboratory supplies to test filter efficacy and for additional testing of samples at the household level during the survey was contributed to the project from Dr. Lantagne's discretionary funding at Tufts University.

Additionally, preparation for the filter manufacturing site visits and survey was supported by the IPA from CDC to Tufts University to support a portion of Professor Lantagne's salary and travel costs.

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Annexes

Annex A:	Certification Scheme – Ceramic Manufacturing Facility Questionnaire
Annex B:	Certification Scheme – Facility Visit Protocol
Annex C:	Certification Scheme – Facility Visit Protocol (filled out for Haiti)
Annex D:	DR FilterPure Site Visit Report
Annex E:	DR Atabey Site Visit Report
Annex F:	Guatemala Ecofiltro Visit
Annex G:	Haiti FilterPure Site Visit Report