CHARACTERIZING THE INFLUENCE OF DISTRIBUTING ORGANIZATIONS ON HOLLOW FIBER MEMBRANE FILTER ADOPTION

A Thesis
by
TYREE WILMOTH

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APPROVED BY:

Jeff Ramsdell, PhD
Chairperson, Thesis Committee

Marie Hoepfl, EdD
Member, Thesis Committee

Jeremy Ferrell, PhD
Member, Thesis Committee

Brian Raichle, PhD
Chairperson, Department of Sustainable Technology and the Built Environment

Mike McKenzie, PhD
Dean, Cratis D. Williams School of Graduate Studies

Abstract

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Tyree Wilmoth
B.S., Centre College
M.S., Appalachian State University

Chairperson: Dr. Jeff Ramsdell

The World Health Organization reports that at least two billion people use drinking water contaminated by fecal matter, which is directly linked to increased risk of developing water-related illness and disease (WHO, 2020a). Household water treatment (HWT) products, such as hollow fiber membrane (HFM) filters, provide an interim solution to point-of-use water treatment in low-income communities. There are a variety of factors that affect whether the beneficiary of a water treatment product adopts the technology, whether they be technological, cultural, psychosocial, or situational. Yet little research focuses on implementing organizations' awareness of or impact on these factors that affect HWT adoption.

This research characterizes the intervention methods used by 23 organizations that distributed HFM filters. An adoption domain framework is applied to survey responses to quantify the organizations' sensitivity to factors of adoption that fall within five adoption domains: (1) User Preferences, (2) Integration and Collaboration, (3) Government Influence, (4) Resources and Communication, and (5) User Training. Statistical analysis is used to assess the relationship between organizations' sensitivity to domains and what they define as indicators of successful adoption. Results show that HFM distributing organizations are most sensitive to the User Training domain and least sensitive to the Government Influence domain. Organizations that have robust monitoring and evaluation are likely to define successful filter adoption through follow-up evaluation. Organizations that are sensitive to accessibility of resources and communication channels are likely to define filter adoption as reported satisfaction and increased filter demand. And lastly, organizations that are aware of user preferences are likely to view self-reported evidence of improved health and the filter's presence during follow up as successful adoption indicators.

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I would like to thank the individuals representing the organizations that participated in this research study and who are dedicating their lives' work to making clean water more accessible to individuals and communities around the globe. I would also like to thank my thesis committee members who have supported and guided my research: Dr. Marie Hoepfl, Dr. Jeremy Ferrell, and Dr. Jeff Ramsdell. Thank you especially, Dr. Ramsdell, for your expertise and guidance throughout this endeavor.

Dedication

In dedication to the memory of my grandpa, Carey Walter Wilmoth. Thank you for always encouraging me to ask the difficult questions and to pursue my passion.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

The issue of access to safe, potable drinking water is a “wicked problem” by definition. This means that it is an issue that cannot be remedied by enacting any particular “solution,” for it is dependent on interlinked processes and variables complicated by multiple unpredictable human and environmental factors (Cockerill & Armstrong, 2015). For example, the infrastructure may exist to treat a community’s drinking water, but many variables may hinder proper adoption and efficacy of such a system. Factors that affect appropriate use of household water treatment systems may be technological, cultural, social, economic, and/or environmental. Barriers to use may include a water treatment product’s undesirability, impracticality, or difficulty to use (Murray et al., 2019). Aesthetics of devices and storage receptacles also largely affect adoption (Ojomo et al., 2015), and there may be a perceived belief that water treatment is unnecessary, even if evidence of water contamination is confirmed (Hulland et al., 2015; Murray et al., 2019).

Another aspect that characterizes water insecurity as a wicked problem is its expansive scope. The World Health Organization (WHO) (2020a) states that in 2017, 2.2 billion people did not have access to safely managed drinking-water services, which are defined as local reservoirs free of contamination and available when needed. In addition, “at least 2 billion people use a drinking water source contaminated with faeces” (World Health Organization [WHO], 2020a, l. 4). Water contamination and poor sanitation are directly related to increased risk of water-related diseases. In many cases, however, disease can be prevented with suitable access to clean water and sanitation. For example, it is estimated that

829,000 people die every year from diarrhea, and water quality and sanitary intervention can render it largely preventable (WHO, 2020a). Effective household water treatment products, when used correctly and consistently, can reduce diarrheal disease by as much as 61% (WHO, 2019). Therefore, the scope of the issue of water insecurity is enormous and complex, which means that it cannot be solved or ameliorated simply with the introduction of technological fixes. The *context* in which people are introduced to water treatment technologies must be evaluated and understood to better predict how effective a specific water treatment system will be within a home or community.

Purpose of the Study

Ideally, all people should have access to safe, potable water piped directly into their homes. Water security is linked not only to improved health, but also to economic development, days gained in work and school, and women's empowerment (Stockholm International Water Institute [SIWI] & World Health Organization [WHO], 2005). However, the immense infrastructure and upfront costs required to equip all communities with potable tap water remains a looming barrier. Household water treatment and safe storage (HWTS) technologies are a suitable interim solution to universal piped-water because they are cost effective and can be easily distributed to and adopted by vulnerable populations. In addition, they can be effective at improving the microbial water quality and reducing diarrheal disease if used appropriately (WHO, 2007).

When distributing organizations contact households in low and middle-income countries that are in need of water treatment, they introduce their technologies and teach the intended users, or beneficiaries, how to operate them. This *intervention process* is characterized as the support these organizations offer to transition the technology into each individual's home. This support may take the form of a demonstration on how a technology works, advice on how to determine if it is functioning properly and what to do if it is not, supplemental information, and/or follow-up visits to ensure appropriate adoption.

There are a variety of factors that might inhibit beneficiaries from appropriately using water treatment products, whether they be technological, cultural, socioeconomical, or situational. The purpose of this study is to characterize the intervention processes employed by aid organizations that distribute hollow fiber membrane filters for household use and determine their sensitivity to these factors that affect filter adoption. Most academic research quantifies the success of household water treatment technologies by the products' ability to reduce diarrheal disease and microbial contamination. But if household water treatment products are not adopted and used appropriately in the first place, what value does the technology have? The methods and resources employed by hollow fiber membrane filter distributors during intervention are important to quantify and compare because they can uncover why certain intervention techniques are more successful than others at fostering appropriate and consistent use.

The Research Questions

This research study characterizes the intervention processes employed by nonprofits or nongovernmental organizations that distribute hollow fiber membrane (HFM) water filters like the Sawyer PointONE™ filter, the Village Water VF100 filter, and the Uzima UZ-1 filter. The research question and sub questions which are answered by this study are stated as follows:

Research Question:

How sensitive are hollow fiber membrane distributors to barriers and enablers of adoption, and does this sensitivity influence their definition of “successful” filter adoption in household settings?

The following individual sub-questions are addressed in the study and are used to answer the research question.

Sub-Questions:

1. What intervention methods do organizations use to distribute HFM filters to households?
2. How sensitive are these organizations to barriers and enablers of filter adoption?
3. How do these distributing organizations define and measure successful adoption of HFM filters?

Significance of the Study

As apparent as it may seem, one of the most effective strategies for increasing adoption is to focus on the users (Clasen, 2009). It is important to understand not only how users can most benefit from water treatment products, but also their need and will to use them. Technological intervention must be sensitive to the social and cultural context in which the technology is used as well. This study pinpoints the intervention practices used by the HFM distributing organizations interviewed in this study. An adoption domain framework is defined, applied, and evaluated to determine the organizations’ sensitivity to different factors that affect HFM uptake and household use. Based on these research findings, recommendations are made to integrate academic analysis with knowledge gained in the field by distributors, thus making household water treatment systems like HFM filters more effective for those who need them most.

Oftentimes, in a traditional top-down transfer of technology approach, the technology is developed and tested in the lab before it is introduced to the people who intend to use it. In most cases, there is either very little collaboration between academia and on-the-ground organizations or few interactions between those who design and those who use the technology (Bhattacharjya et al., 2019). These implementing programs can have low rates of adoption because the technologies do not suit the needs or wants of the intended beneficiaries. *Appropriate technology* involves an integrated approach where users have a direct say in how technologies are designed and managed. This concept of appropriate technology was originally coined as “intermediate technology” by economist Dr. Ernst Friedrich Schumacher in his 1973 work *Small is Beautiful* (Schumacher, 1973). Technologies that are deemed “appropriate” are sustainably sourced and must be compatible with local, cultural, and economic conditions.

For the purposes of this study, it is crucial to be aware of the appropriateness—or lack thereof—of a specific water treatment product within the household setting. Nongovernmental organizations and nonprofits benefit from having access to local networks and knowledge when it comes to addressing the needs of the community. This study is taking advantage of their unique position to bridge the gap between academic research and real-world implementation and adoption. By highlighting the intervention techniques, resources, and communication networks that these organizations offer to water-insecure households, we can better understand how they impact adoption and consistent use of household water treatment technologies.

Organization of the Research Study

This section provides an overview of the contents of the following chapters in this research paper. Chapter 2 provides a review of the relevant literature and explains how this research study fills a gap in the understanding of how distributing organizations influence the adoption of HFM filters as household water treatment technologies.

Chapter 3 details the methodology used to gather and analyze data for this study. A survey instrument was developed and used to gather data on the target organizations' filter program, intervention methods, and definition of successful adoption. The term "intervention methods" refers to the tactics employed by distributing organizations to influence beneficiaries to use and value their filters, such as supplemental resources, demonstrations and filter training, community or peer influence, and broader Water, Sanitation and Hygiene (WASH) education. An organization's "sensitivity" to adoption, as referenced in the research questions, is defined as an organization's awareness and responsiveness to five domains of filter adoption: (1) User Preferences, (2) Integration and Collaboration, (3) Government Influence, (4) Resources and Communication, and (5) User Training. These adoption domains were operationalized from the survey responses and then weighed and combined. As a result, each organization has a score in each of the five adoption domains. Because "successful adoption" varies according to the organization's goals and objectives in the filter program, this research aims to identify the organization's definition of successful adoption and to determine if there is a relationship between how an organization defines success and how sensitive they are to the various adoption domains.

Chapter 4 outlines the results of the individual survey questions and identifies trends across the intervention methods employed. This chapter also contains the results of the domain scores for each organization, as well as the results of the statistical analysis used to analyze the relationship between adoption domain scoring and specific indicators used for defining successful adoption. The final chapter, Chapter 5, contains discussion and conclusions based on the study results and identifies opportunities for future research.

Chapter 2: Review of Literature

Overview of Household Water Treatment

Household water treatment (HWT)—sometimes more specifically referred to as household water treatment and safe storage (HWTS)—consist of methods, technologies, and devices that treat unsafe, unreliable, or unimproved water sources (WHO, 2020b). Various technologies and interventions have been proposed to empower individuals in low and middle-income countries to control the quality of their water while decreasing their risk of diarrheal disease. Point-of-use (POU) water treatment techniques like boiling, chemical disinfection, solar disinfection, and combined treatment systems are commonly used when resources are scarce or in emergencies (WHO, 2013). Household water treatment technologies like membrane and ceramic filtration are also effective at treating unsafe water supplies (WHO, 2019). Different water treatment techniques are suitable for different types of contaminants and environmental conditions, so the following sections explore a brief overview of POU household water treatment products and their usefulness as agents of water treatment.

The Importance of Safe Storage

It is possible that water can be re-contaminated after proper purification or filtration if it is placed in a receptacle that is unsterilized, open-air, sealed improperly, or if the water is accessed with a contaminated cup instead of through an external spout. The U.S Centers for Disease Control and Prevention (CDC) defines "safe storage" as a plastic, metal, or ceramic container that has the following barriers to recontamination:

- A small opening with a lid or cover that discourages users from placing potentially contaminated items, such as hands, cups, or ladles, into the stored water;
- A spigot or small opening to allow easy and safe access to the water without requiring the insertion of hands or objects into the container; and,
- A size appropriate for the household water treatment method, with permanently attached instructions for using the treatment method and for cleaning the container. (Centers for Disease Control and Prevention [CDC], 2012, para. 3)

To reduce risk of post-filtration contamination, some household water treatment systems route the filtered water directly to an accompanying storage container, like the Uzima filter systems. Safe storage is such an important component of water treatment that the WHO has promoted the acronym HWTS (Household Water Treatment and safe Storage) over HWT (Household Water Treatment) (WHO, 2020b).

Pasteurization and Disinfection

Solar-Driven Technologies. Pasteurization is the process of maintaining water temperature higher than 63°C (145°F) for more than 30 minutes to disinfect water (Bitton, 2014). Various solar pasteurization (SOPAS) technologies take advantage of the sun's radiant energy to maintain pasteurization temperatures (Bitton, 2014; Strauss et al., 2016). Solar disinfection (SODIS), more specifically, uses ultra-violet and infrared radiation from the sun to inactivate harmful microbes like fecal coliforms (Clasen, 2009; Strauss et al., 2016). One of the simplest and lowest-cost SODIS techniques involves filling clear, plastic bottles with water and exposing them to the sun for at least six hours. Suspended particles should be filtered out before pasteurization for optimal results (Center for Affordable Water and Sanitation Technology [CAWST], 2021h; Clasen, 2009). When water is drank directly from the bottle, it acts as a safe storage container and prevents recontamination (CAWST, 2021h).

Boiling. Boiling is also an effective pasteurization method if it is maintained at a "rolling" boil for 1 to 3 minutes, depending on the altitude (WHO, 2013). According to Clasen (2009), "[boiling] is the most prevalent means of treating water in the home; it is practised by hundreds of millions of people, perhaps because the necessary hardware are already available in most cases" (Clasen, 2009, p. viii). As one of the oldest methods of water disinfection, it is also one of the most effective because it has been shown to kill or inactivate waterborne pathogens that are small enough to endure filtration or resist chemical disinfection (Clasen, 2009; Rosa et al., 2010). Although boiling is an effective means to improve the microbiological quality of the water worldwide, it has a few disadvantages. It is energy intensive (meaning it can be higher cost than alternative treatments), the water is susceptible to recontamination, and boiling can contribute to the unintended consequence of increased air pollution in the home due to the combustion of biomass fuel (Bitton, 2014; Clasen, 2009; WHO, 2013).

Chemical Disinfection

A variety of chemicals can disinfect water, but chlorine is most commonly used to provide protection against waterborne pathogens. Chlorination in conjunction with safe storage has been promoted by the CDC and Pan American Health Organization as an effective water improvement method in low-income communities (Bitton, 2014). Chlorine products, like sodium hypochlorite, may be in the form of a liquid, powder, or tablet (WHO, 2013). Some of the chlorine reacts with organic matter and pathogens through oxidation, and some excess chlorine that is not combined can serve to prevent recontamination (CAWST, 2021d). Another less common product that uses chlorine disinfection is the electrochlorinator, which converts salt and water into sodium hypochlorite via the process of electrolysis (Murray et al., 2019).

Filtration

Biosand filters are popular HWT solutions that utilize gravity to pull water through a stratified granular medium covered by a biological film (Bitton, 2014). They are useful in treating water with high turbidity, or high concentration of suspended particles of sediment, algae, dissolved organic compounds, or other microscopic organisms. High turbidity usually indicates risk of human health because metals, pathogens, and other bacteria can attach to the suspended material (United States Geological Survey [USGS], n.d.). The biosand filter vessels can be made from concrete, plastic, or stainless steel. Contaminated water is poured into the top of the column, and the microorganisms that colonize the sand inactivate or trap the pathogens. Because the outlet tube is higher than the sand surface to maintain static head, a new batch of water has to be poured in to get filtered water to flow out (CAWST, 2021a). Some advantages of biosand filters are their low cost, durability, ease of use, and relatively high flow rate.

Another popular filtration device is a ceramic filter, which may take the form of a ceramic pot, ceramic disk, or a “candle” made from a hollow cylindrical form. To make the filter, clay is mixed with a combustible material (like flour, rice, or sawdust) and applied with colloidal or nanosized silver to inactivate the microbes, and then the filter is fired in a kiln. Contaminated water is poured into the filter, and water passes through the pores of the filter and is collected in a lower container which can be protected from recontamination (CAWST, 2021b). Data show that in the long term ceramic filters can be more effective than biosand and SODIS technologies (Bitton, 2014). However, the filter requires regular cleaning, and small cracks can form over time and compromise the filter's effectiveness (CAWST, 2021b).

Many water treatment systems make use of two or more processes to ensure effective water treatment. A method to quicken the sedimentation process is by adding natural coagulants (like moringa seeds or prickly pear cactus) or chemical coagulants (like aluminum sulphate, polyaluminium chloride, or iron salts) (CAWST, 2021c, 2021f). Particles that cause turbidity are typically negatively charged (like sand, silt, and clay), so they bind with the positively charged coagulants to form larger, heavier particles called flocculants. These particles are then easier to settle out or be filtered (CAWST, 2021f). Chlorine products are often mixed with coagulants (like Fe or Al salts) to more effectively bind with suspended organisms or organic material, and the water is then passed through a cloth to separate out the agglomerate solids (Bitton, 2014; CAWST, 2021c). It is also a common practice to filter out flocculants and sediment with a biosand filter or cloth before processing with one of the pasteurization or disinfection techniques mentioned above.

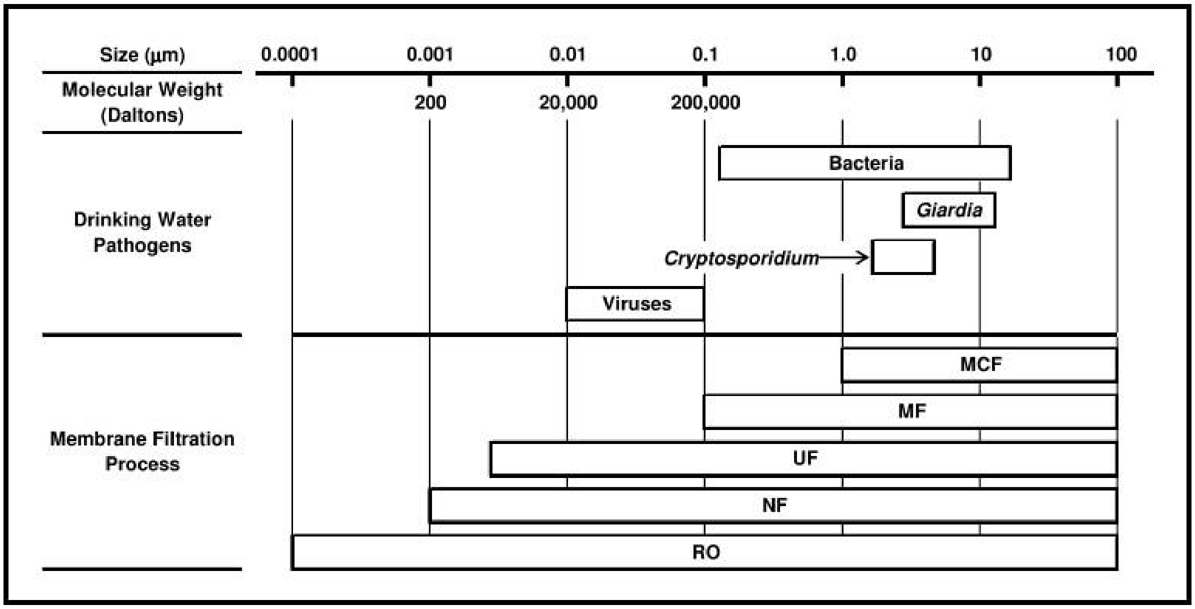
Membrane Filtration

Membrane filters are attractive water treatment options because they serve as a physical barrier against contaminants, remove turbidity, enhance water taste, and the cost of the technology has decreased over the past two decades (Peter-Varbanets et al., 2009). Membrane filtration is defined by the US Environmental Protection Agency (EPA) as "a pressure- or vacuum-driven separation process in which particulate matter larger than 1 [microns] is rejected by an engineered barrier, primarily through a size exclusion mechanism and which has a measurable removal efficiency of a target organism that can be verified through the application of a direct integrity test" (United States Environmental Protection Agency [USEPA], 2005, p. xxiv). The most common membrane filter classifications are microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. Microfiltration, which is the main type of filtration process used in the products distributed by organizations surveyed in this study, is "a pressure-driven membrane filtration process that typically employs hollow-fiber membranes with a pore size range of approximately 0.1 – 0.2 [microns]" (USEPA, 2005, p. xxv). When pore sizes are stated by a manufacturer in microns, the specified pore size can be either nominal (the average pore size) or absolute (the maximum pore size). A micron is one millionth of a meter, or 1 x 10^{-6} meters.

As demonstrated in Figure 1, microfiltration (MF) provides protection against a range of bacteria, *Giardia* cysts, and *Cryptosporidium* oocycsts. Ultrafiltration (UF), on the other hand, is favored over microfiltration in cases where it is necessary to remove viruses because its pore sizes can be much smaller, generally ranging from 0.01 to 0.05 microns or less. Though highly effective at removing microbiological contaminants, nanofiltration (NF) and reverse osmosis (RO) are most commonly used to remove dissolved contaminants in situations like desalinization. Additionally, they depend on semi-permeable membranes that do not have distinct pores (USEPA, 2005).

Figure 1

Filtration Application Guide for Pathogen Removal



Note. Reprinted from *Membrane filtration guidance manual* (p. 2-3), by United States Environmental Protection Agency, 2005.

The CDC has established a guide to the effectiveness of POU household water treatment technologies (CDC, 2008). The pathogen removal ratings are "not effective," "low effectiveness," "moderate effectiveness," "high effectiveness," and "very high effectiveness." These ratings are applied to four categories of water contaminants: Protozoa (like *Cryptosporidium, Giardia*), Bacteria (like *Campylobacter, Salmonella, Shigella, and E. coli*), Viruses (like Enteric, Hepatitis A., Norovirus, and Rotavirus), and Chemicals. The CDC clasifies microfiltration as yielding very high effectiveness at removing protozoa, moderate effectiveness in removing bacteria, and no effectiveness at removing viruses and chemicals. The pathogen removal rating for ultrafiltration is very high effectiveness for the contaminant categories of protozoa and bacteria, moderate effectiveness at removing viruses, and low effectiveness in protecting against chemicals (CDC, 2008).

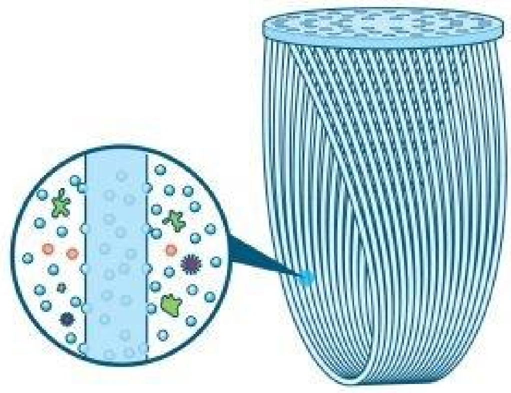
Hollow Fiber Membrane Filters

Hollow fiber membrane filters are the type of membrane filters distributed by the organizations selected to participate in this research study. The four types of filters distributed by the participating organizations are the Sawyer PointONE™ and Point ZeroTWO filters, the Uzima UZ-1 filter, and the Village Water VF100 filter. All of these filtration products are hollow fiber membrane (HFM) filters, but they vary by manufacturer, pore size, and the setup of the filtration system.

HFM filters are constructed from hollow fibers arranged into what is called a "membrane module" (USEPA, 2005). Hollow fiber modules are most commonly comprised of long, narrow hollow fiber tubes bundled longitudinally. Whether via forced pressure or gravity flow, contaminated water enters the pores of the hollow fiber tubes within the module, and contaminants larger than the pore size are trapped and left behind (refer to Figure 2). Filters must be frequently backwashed using water and a device like a syringe, especially if the water is turbid. The hollow fiber membrane products distributed by the organizations of interest in this study are not designed to remove dissolved solids, chemicals, or heavy metals. Instead, they target bacteria, protozoa, and waterborne pathogens.

Figure 2

Schematic of Hollow Fiber Membrane Filter



Note. Reprinted from *Water filtration: Hollow fiber membrane technology*, by Sawyer, 2020, from https://sawyer.com/water-filtration/. Reprinted with permission.

Sawyer Filters. The Sawyer PointONE™ filter is a point-of-use filter that allows water to be gravity-fed through a bundle of hollow filter membranes with 0.1 micron absolute pores. Sawyer advertises that the PointONE™ filter screens out "harmful bacteria, protozoa, or cysts like E. coli, Giardia, Vibrio cholerae and Salmonella typhi" (Sawyer, 2020). The filter is promoted for recreational activities like backpacking, disaster relief, and as a water treatment option for families in low-income communities. The Sawyer Bucket Adapter system is designed for household water treatment in a "hanging" configuration, where water is poured into a bucket and then delivered by a hose at the base of the bucket to an in-line filter, as shown in Figure 3 (Sawyer International, 2021). Sawyer states that a safe storage container is unnecessary unless large quantities of water are needed at one time (Sawyer, 2020). If users want to store clean water instead of filtering directly into a drinking receptacle, they would need an additional surface to set a clean water receptacle to which the filter could be routed. The average flow rate is approximately one gallon every 5 to 7 minutes, and the factory price is $60, although it is offered at a discounted price to nonprofit distributors (CAWST, 2021g). Sawyer claims that its water filters can last 10 years or more if properly maintained (Sawyer International, 2021).

Figure 3

Sawyer PointONE™ Filter and Bucket Adapter System

Note. Reprinted from *Bucket adapter kits*, by Sawyer International, 2021, from https://international.sawyer.com/products/bucket-adapter-kits/. Reprinted with permission.

The Sawyer PointONE™ filter is the most common filter distributed by organizations in this study, but a few also distribute the Sawyer MINI and Sawyer Point ZeroTWO filters in their HFM program. The Sawyer MINI filter is a PointONE™ filter that can be screwed onto the included drinking pouch or a standard disposable water or soda bottle. Water is squeezed from the pouch or bottle through the filter to filter out contaminants greater than 0.1 microns, and it is recommended to backflush and sanitize the filter with a syringe after use. Sawyer offers the Point ZeroTWO filter as option for filtering water that is contaminated with viruses. The Point ZeroTWO filter is an ultrafiltration product because its absolute pore size is 0.02 microns as the name suggests, which is within the range of 0.01 microns to 0.05 microns (USEPA, 2005).

Uzima Water Filter. The Uzima and Village Water filters use similar hollow fiber membrane technology. Uzima UZ-1 filters, or household water filters, have absolute 0.1 micron hollow fibers (Uzima Water Filters, 2021a). The filtration system is in a "tabletop" configuration, meaning the filter is threaded into the bottom of a five-gallon bucket, which is set on top of and threaded through another five-gallon bucket with a lid for safe storage. As seen in Figure 4, water flows from the top bucket through the filter into the bottom bucket, and clean water can be accessed by a tap at the base. The flow rate is approximately one gallon per four minutes with non-turbid water, and the factory cost of a UZ-1 filter kit, not including the bucket, is $30 (CAWST, 2021i). One advantage of the Uzima filter system is it only requires one surface and it has a clean water storage receptacle incorporated within to prevent re-contamination. The filter is cleaned by backwashing clean water using a syringe. Similarly, the UZ-2 model is a complete water filtration system that includes cuboid nesting buckets with the filter inside and a tap at the base of the lower bucket for accessing the filtered water. Uzima claims that their filters are designed to last up to 10 years with proper use and maintenance (Uzima Water Filters, 2021a).

Figure 4

Uzima UZ-1 Filter System (Image Source: Uzima Water Filters, 2021)

Note: Clear buckets are for demonstration only. Reprinted from *Our products: UZ-1 household water filter*, by Uzima Water Filters, 2021, from https://uzimafilters.org/our-products/uz-1/. Reprinted with permission.

Village Water Filter. Village Water Filter is a non-profit corporation with a goal to "produce a low cost water filter that will reduce pain, suffering and death caused by consuming unclean water" (Village Water Filters Inc., 2018b). The Village Water Filter uses absolute 0.1 micron hollow fiber membrane technology in its VF100 model. The filter can be attached to a water reservoir like a bucket in a "hanging" configuration and be gravity fed, just as the Sawyer Bucket Adapter System. It can also be attached to a reticulated carbon foam pre-filter, the VF200. The VF100's flow rate in the bucket system is approximately one gallon per four minutes, and the factory price is $25 (CAWST, 2021j). The manufacturer emphasizes that the filter should last years with proper maintenance (Village Water Filters Inc., 2018b).

WHO Guidelines and Classification of HWT

Despite there being various filtration types, it is important to evaluate their effectiveness at microbial reduction using a standardized procedure and classification system. The WHO has established a set of guidelines that classify HWTS technologies under three categories based on their performance in laboratory conditions: 3-Star, 2-Star, and 1-Star, which were previously termed "Highly protective," "Protective," and "Interim," respectively (WHO, 2011). Three classes of target pathogens—bacteria, viruses, and protozoa—are used to determine these performance categories. Because of the lack of sufficient, available data and the inability to classify all potentially harmful waterborne pathogens, three "reference pathogens" are used to represent the three classes of target pathogens (WHO, 2011). "The reference pathogens for bacteria (*Campylobacter jejuni*), viruses (rotavirus) and protozoan parasites (*Cryptosporidium*) were selected because they are relatively well characterized, of high public health importance and conservative with respect to dose–response and infectivity" (WHO, 2011, p. 3). Performance targets are expressed as $\log_{10}$ reductions in microbe concentrations (computed as $\log_{10}$ ($C_{untreated\ water}/C_{treated\ water}$), where C is microbe concentration) (WHO, 2011, p. 2). As demonstrated in Figure 5, 3-Star classification results in at least 4 log reduction in bacteria and protozoa and 5 log reduction in viruses, 2-Star classification has at least 2 log reduction in bacteria and protozoa and 3 log reduction in viruses, and 1-Star must achieve 2-Star targets for two of the three classes of pathogens, as well as provide evidence for obvious health gains.

Figure 5

WHO HWT Performance Criteria

Performance classification	Bacteria (log_{10} reduction required)	Viruses (log_{10} reduction required)	Protozoa (log_{10} reduction required)	Interpretation (with correct and consistent use)
★★★	≥ 4	≥ 5	≥ 4	Comprehensive protection
★★	≥ 2	≥ 3	≥ 2	
★	Meets at least 2-star (★★) criteria for two classes of pathogens			Targeted protection
–	Fails to meet WHO performance criteria			Little or no protection

Note. Reprinted from *Results of round II of the WHO scheme to evaluate household water treatment technologies* (p. 2), World Health Organization, 2019.

Certification of HFM Products

The following is an overview of the certification of the filters distributed by organizations surveyed in this study. Laboratory testing of the Sawyer PointONE™ filter shows that the membrane filter performs at 5 log reduction of protozoan parasites and 6 log reduction in bacteria, which exceeds the EPA's recommendations and which would be considered 3-Star by the WHO's standards (Hydreion Labs, 2005). Sawyer's Point ZeroTWO filter removes viruses at a greater than 5.5 log (99.9997%) rate. According to WHO's evaluation of the VF100 Home Filter in 2020, the filter is assigned 6 log reduction for protozoan, and it meets *Targeted protection* against bacteria and protozoa (WHO, 2020c). It is rated at 1-Star protection because it meets targets for two of the three microbial groups. The Uzima UZ-1 filter was tested in 2015 by the independent BNC Research Laboratories using two fecal coliforms and E. *coli*. The results were that the overall effective removal is greater than 6 log (BNC Research Laboratories Inc., 2015). In the 2019 evaluation by the WHO, the UZ-1 filter meets 1-Star, or *Targeted protection*, against the bacteria and protozoa categories (WHO, 2019). Though meeting guidelines for removing contaminants is evidence of an effective filtration product, the protection claimed by these evaluations will not be consistent in the field if they are not used and maintained properly. As indicated in Figure 5, WHO's interpretations of the assessed protection are based on "correct and consistent" use.

Lab vs. Field Performance

In a 2016 publication, the WHO evaluated eight products that represent solar, chemical, filtration, and ultraviolet technologies. This was the first global assessment of HWT performance, and it determined that, although many HWT products met WHO performance targets, "product evaluation and regulation is generally weak." The institution stated that "…market development and user needs and motivations for standard use" need to be better understood (WHO, 2016, p. 7). In its second round of HWT product evaluation in 2019, the WHO recommended that implementers should choose HWT products that meet at least minimum performance criteria, but that product choice should also be dependent on "water quality conditions in targeted locations, familiarity, supply chains and other factors that impact correct and consistent use" (WHO, 2019, p. 59). Therefore, the standards that are met in the laboratory for HWT effectiveness are not necessarily the only criteria for predicting microbial removal, nor are they indicative of how the technologies will perform in people's homes.

It is crucial to recognize that the WHO performance ratings are dependent upon HWT technologies being tested in a laboratory setting (WHO, 2011). Short-term randomized controlled trials are then conducted to determine the HWT's potential to reduce diarrheal disease. However, these tests are conducted under very controlled or idealized circumstances and do not reflect real-world performance. Field studies have consistently found that water treatment efficacy is higher when measured in the lab than in households (Bitton, 2014;

Brown et al., 2008, 2009; Levy et al., 2014; Murray et al., 2017, 2019; Reller et al., 2003). For example, Bitton (2014) identified inconsistencies in biosand filters' capability at reducing *E. coli* in the field (between 0% and 99.7%) compared to laboratory results (average of 94% reduction). Levy et al. (2014) conducted household studies near coastal Ecuador and found a significant difference between the efficacy of chlorine for water treatment in the lab versus its effectiveness in households. They found that water treated with chlorine achieved microbial levels safe for drinking only 34% to 51% of the time, largely due to the variety in source water and household conditions. Studies like these show that even though HWTs might pass lab testing with flying colors, projected health gains fall short when these technologies are deployed in households.

HFM Filter Performance

The hollow fiber membrane technologies distributed by organizations surveyed in this study are at various levels of product evolution. The Center for Affordable Water and Sanitation Technology (CAWST), which catalogues HWT solutions and provides information on the microbiological performance, operation and maintenance, and research on the products has a product progression labeling system that progresses from "Emerging," "Tested," "Adopted," and "Established" (CAWST, 2021e). CAWST has labeled the Sawyer PointONE™ filter as "Adopted" (CAWST, 2021g), the Uzima UZ-1 filter as "Adopted" (CAWST, 2021i), and the Village Water Filter VF100 as "Tested" (CAWST, 2021j). Therefore, most research studies mentioned in this section discuss the performance and adoption of the Sawyer PointONE™ and Uzima UZ-1 filters because they have been studied in the field.

A team of researchers from the CDC conducted an independent evaluation of a membrane filter distribution program led by a non-governmental organization in 33 Honduran villages (Fagerli et al., 2018). In 2016, after baseline data was collected, Sawyer and Uzima 0.1 micron filter tabletop systems were sold to participating households at a subsidized price, and community members were trained on how to use and maintain the filters. The CDC's evaluation conducted within 6 to 12 months of the distribution showed that HFM purchase and use were high and sustained in the sample households. Use of water treatment by filtration increased from a baseline of 19% to 85% ($p < 0.001$), and purchase of bottled water decreased from a baseline of 44% to 6% ($p < 0.001$). However, although filter use was reported as high, approximately one third of drinking water samples did not meet WHO drinking water quality guidelines for *E. coli* contamination. The research team concluded that the gap between the top and bottom buckets may have allowed for post-filtration contamination. This study shows that although adoption and use of HFM filters may be high, water treatment may not be effective due to environmental or contextual factors.

Sawyer PointONE™ filter (along with biosand and ceramic filter) intervention effectiveness was evaluated in Haiti in response to the 2010 earthquake and resulting cholera outbreak (Rayner et al., 2016). Rayner et al. conducted household surveys and tested both untreated and treated water approximately eight months after the distribution of free Sawyer filters in 2014 to 98 households. The research group found that 57% of the 46 sample households reported filter use, and use was confirmed in 54% of surveyed households. In addition, approximately one third of samples taken directly from the filters had detectable levels of *E. coli*, which meant there was relatively low reduction of contaminants. Rayner et al. concluded that not requiring cash investment for the filters, distributing to households that relied primarily on improved water sources (and thus limiting potential risk reduction), and not providing consistent follow ups and supply chain access may have attributed to the low adoption rates of the Sawyer filters (Rayner et al., 2016).

HFM filters are attractive for water treatment, yet their effectiveness can be hindered by fouling, or blockage of the membrane by microbial or inorganic components. Oftentimes, fouling can be reversible by back-flushing the filter with air or clean water, but fouling can also require removal using chemicals (Murray et al., 2015). Although Sawyer advertises that the PointONE™ filter has approximately a ten year lifespan, a research group from Tufts University in 2015 found that six filters used in Honduran homes were “irreversibly fouled and non-functional after [less than] 2 years of use” (Murray et al., 2015, p. 220). While this study revealed the fouling layer and decreased performance of the filters over two years, it did not verify if the households were using the filters appropriately for the duration of their 23-month use. In addition, a reviewer of the study expressed concern that contamination and microbial growth could have occurred in the two months between when the filters were taken from the field and when they were analyzed in the lab, thus affecting the study’s results (Lindquist et al., 2015).

In their 2017 publication, Murray et al. surveyed households who had been using the PointONE™ filter for one or three years. Laboratory testing of a new PointONE™ control yielded more than 99.98% total coliform reduction. Even though most filters from the field showed significant improvement in water quality, less than one third met the WHO’s microbiological guidelines and “18% had *more E. coli* in the filtered water than in the source water” (Murray et al., 2017, p. 81). The study also reported that several households abandoned filters, though users had been trained on how to use and maintain them. This study highlights the need to better quantify HWT efficacy in the field over time, as well as the role that intervention has in appropriate adoption.

Oftentimes, WASH or HWTS interventions are solely quantified by the percent reduction in microbial disease or contamination. However, not every intervention is conducted in the same way or with the same resources. Reduction of diarrheal disease, for instance, is an outcome of how effective the technology is *and* how appropriately the beneficiaries are using it, assuming they are well equipped with the proper knowledge and skills to do so. Yet it has not been until recently that quantifying and understanding peoples' relationships with their water treatment technologies have been highlighted as valuable indicators of successful adoption. The following section will explore the factors that influence how people adopt water treatment technologies.

Enablers and Barriers to Effective HWT Use

In order to experience measurable health gains, users must maintain consistent use of water treatment products. For example, interruptions in water treatment that decrease a user's adherence from 100% to 90% can reduce predicted health gains by as much as 96% (Clasen, 2015). There are multiple barriers—ranging from deliberate choice to circumstantial—that inhibit appropriate and consistent HWT adoption. These barriers to appropriate use fall under a variety of reasons, including the technology is not aesthetically appealing, it is difficult to use, there is limited access to repair services if it is broken, or even the perception that treating drinking water is not necessary (Murray et al., 2019). Several studies show that one important contribution to the disuse of water treatment products over time is technology breakage and lack of access to replacement parts and filters (Brown et al., 2009; Clasen et al., 2006; Coulliette et al., 2013). For the HFM Sawyer filter, there is documentation that blockage and breaking, issues with the backwashing syringe, and failing to adhere to the requirement to regularly clean the filter have led to inconsistent use over time (Kohlitz et al., 2013; Murray et al., 2015, 2017). The CDC's report on the Sawyer and Uzima filter distributions in Honduras indicates that focus group discussions identified themes of adoption barriers, including that the syringes broke easily and that there was no clear way to replace broken filter parts (Fagerli et al., 2018). These issues are compounded by the fact that reliable supply chains can be difficult to procure in underserved areas.

The Importance of Personal Preference

Personal preference, influenced by culture and social factors, can be influential on a user's HWT choice. In their 2017 study on hollow fiber membrane microfilters, Murray et al. found their results were consistent with others: water treatment technologies are often chosen by consumers based on their convenience and design appeal rather than their efficacy as a tool to improve water quality. Ojomo et al. echo these results, quoting an interviewee discussing the results of a safe storage program in Ghana who said "…it had been observed that containers are purchased based on the color even though they are not always used to store water" (2015, pp. 707–708). Culture and context are also major factors in treatment preference. For example, some populations are more sensitive to the taste and smell of chlorine, so they avoid such water treatment techniques (Reller et al., 2003). Others must treat more turbid water, so they gravitate towards filters that reduce suspended particles. Though water treatment products serve a specific function, the aesthetics of a device are important to users because it can be an expression of personal identity and culture (Ojomo et al., 2015).

It is important that the preferences of users are identified and used in market decision-making so that they can be more appropriate and effective in the field. As Albert et al. (2010) advised: “POU product dissemination at scale to the poor will not occur until we better understand the preferences, choices, and aspirations of the at-risk populations” (p. 4432). Household testing is imperative for new products so that designers can be aware of expectations of performance and potential design flaws before products are disseminated to the public (Murray et al., 2019). In addition, it is the responsibility of the implementers of WASH technologies to relay issues to the manufacturers and distributors so that the needs of users are considered, which necessitates the establishment of robust communication channels and attentiveness to beneficiaries’ preferences and opinions.

Classifying Factors of Adoption

Various literature has focused on how to classify enablers and barriers of HWTS adoption. In 2015, Hulland et al. published a comprehensive review of literature that evaluated the factors that influence sustained adoption of WASH technologies. The research team identified 148 articles, and 44 of those which explicitly reported on sustained adoption. In mapping and synthesizing the reports, they identified three main factors that influence sustained adoption: psychosocial, contextual, and technological. Psychosocial motivators include knowledge of germ transmission, social norms, cues to action, and the need to fulfill a caretaker’s role within the household. They also include the user’s perceived susceptibility to changes in health if a particular behavior is adopted, and the perceived severity of the consequences of not adopting the behavior, and the perceived benefits or barriers of behavior change (Hulland et al., 2015, p. 110). Contextual factors include gender, socio-economic status, education, market accessibility, and environmental influences. And lastly, technological enablers include the product's affordability, durability, local availability, ease of use, and installation and maintenance requirements (Hulland et al., 2015).

Daniel et al. (2018) used Qualitative Comparative Analysis on 41 case studies in Africa, Asia, and South America to analyze the interaction between socio-environmental characteristics that influence successful HWT adoption. They found that a household's perception that their water quality is poor is the most important precursor for successful adoption, though perceived threat alone does not explain HWT adoption. In addition, the absence of prior experience with water treatment practices was consistently associated with successful HWT adoption. The team concluded that no single socio-environmental condition can explain HWT adoption, but that they are complexly intertwined and that a system level approach that considers socio-economic characteristics of households is imperative when establishing a new HWT intervention program (Daniel et al., 2018). In their 2019 publication using data from 451 households in Nepal, Daniel et al. used the Bayesian Belief Network to model the interactions between socio-economic variables (presence of children under 5 years, HWT promotion, education, water source, logistic access, and wealth level) and five psychosocial variables (perceived severity, perceived infection probability, attitude, norms, and ability). They found that education, wealth level, and exposure to HWT promotion were the most influential socio-economic characteristics on HWT adoption. The Psychosocial factors of social norms and the ability or knowledge of how to use the HWT were also influential. The team concluded that it is imperative that socio-economic characteristics of the HWT beneficiary and the psychosocial factors that affect adoption must considered to increase HWT adoption and use (Daniel et al., 2019).

In their research study, Ojomo et al. (2015) evaluated enablers and barriers to the sustainability and scale up of HWTS practices. The research team used key informant interviews, focus group discussions, and online surveys to collect data from 79 individuals who have experience with sustaining and scaling up HWTS practices. The interviews were coded for enabler and barrier factors, the frequency of these factors was identified, and the factors were subsequently condensed into six categories, or "domains": (1) User preferences, (2) Integration and collaboration, (3) Standards, certification, and regulations, (4) Resource availability, (5) Market strategies, and (6) User training. The User preferences domain includes factors of adoption that are directly linked to the preferences of the target beneficiary of HWTS practices. For example, this includes social status achieved or strengthened from engaging in the HWTS practice, how easy it is to use or engage with the HWTS, and cultural or religious beliefs that may impact the uptake of HWTS. The Integration and collaboration domain includes factors of adoption that are influenced by partnerships and integration of the HWTS into other programs. Examples include partnerships with local leaders, health care workers, and teachers, as well as community participation. Standards, certifications, and regulations is a domain comprised of factors that affect adoption like certification of the HWTS practice to influence uptake and government partnership. The Resource availability domain includes factors such as the cost of the product or practice, as well as the availability of other economic and human resources needed to sustain HWTS adoption. Market strategies is a domain made of factors that affect the process of getting the product to the user, such as "effective supply chain, sustainable financing, and competition between the technologies" (Ojomo et al., 2015, p. 707). The last domain, User training, incorporates factors of adoption that affect the ability of HWTS users to effectively use the technologies, including the influence of behavior change education and household follow ups.

After identifying the six domains and defining them, the research team demonstrated how these domains were supported by the Diffusion of Innovations theory, an adoption theory popularized by Everett Rogers and used to model the uptake of technologies and products. The Diffusion of Innovations theory states that the four components that impact the diffusion of an innovation are the innovation itself, time, communication channels, and the social system (Ojomo et al., 2015, p. 710). The research group concluded that all the identified domains must be considered for programs wishing to sustain and scale-up HWTS practices. Ojomo et al.'s six domains and supporting components were modified and served as the basis for the five "adoption domains" applied to the survey responses in the current study to evaluate distributing organizations' sensitivity to factors of filter adoption.

Implementing Household Water Treatment Technologies

HWT Implementers

According to Clasen (2009), there are four main types of implementers of HWT technologies: (1) the public sector, (2) non-governmental organizations (NGOs), (3) NGO/private sector hybrids, and (4) the private sector. Differences in implementers and implementation strategies are dependent on both the target population (such as purchasing power, preferences, and geography) and the water treatment products themselves (such as cost, durability, and portability) (Clasen, 2009). The organizations that are the focus of this research study are primarily nonprofit or NGO organizations with the shared goal of increasing access to water treatment technologies in lower-income communities. Some organizations focus primarily on WASH education and access; for others, water filtration is just one of many related programs that may include education, food access, child sponsorship, and social enterprise. Some of the organizations are affiliated with religious institutions, so their mission includes ministry and outreach to filter beneficiaries.

According to Clasen, implementers may take one of the following basic approaches to water treatment intervention, including:

> 1. providing it free of charge (or for nominal consideration) as a public good,
> 2. providing it at a subsidized price with partial cost recovery, and
> 3. selling it on a commercial basis at a price designed to cover its full manufacturing and sales cost, together with a profit. (Clasen, 2009, p. 14)

The organizations in the current study are primarily donor-supported, and the HFM filters are distributed at little to no charge to the beneficiary.

One of the greatest barriers to HWT uptake can be the product cost (Ojomo et al., 2015). Giving out products free of charge may be a solution to making clean water more accessible to those who have very few resources, but it can create a lack of personal investment that results in product indifference and disuse. Research shows that giving out technology for free can impede the uptake of water treatment solutions (Blanton et al., 2014; Ojomo et al., 2015; Rayner et al., 2016). For example, in Tanzania, an international NGO reported an increase in biosand filter uptake and use after they began selling the filter instead of giving them out for free (Ojomo et al., 2015). One way to promote ownership without requiring financial investment is through implementing “sweat equity,” where beneficiaries assist in the manufacturing, transportation, installation, or training of the products (Clasen, 2009). This promotes self-efficacy and helps to make the beneficiary feel invested in the water treatment process.

HWT Implementation

The Centre for Affordable Water and Sanitation Technology, or CAWST, provides consulting and training for water and sanitation projects and has worked with several hundred implementers since its inception. CAWST has identified common factors for successful HWT programming and implementation. These include: (1) creating and sustaining demand, (2) supplying products and services to meet the demand, and (3) monitoring continuous improvement of program implementation, which are supported by building human capacity and ensuring sustained program financing (Schuelert et al., 2011). For example, in their study on biosand, ceramic, and hollow fiber membrane filter interventions in Haiti, Rayner et al. found programs that distributed effective products, provided safe storage, required cash investment, provided initial training, provided follow-up, provided access to supply chains, targeted households relying on contaminated water sources, and were familiar with the local context were more successful (Rayner et al., 2016). Therefore, these implementers, or distributors, of these products must supply not only the products themselves (the "hardware"), but they must also supply training services (the "software") to ensure the adoption of the HWTs.

It is essential that implementers collaborate with and involve partners and local actors to sustain HWT uptake in households. In 2007, Population Services International (PSI), a social marketing organization with global scope, collaborated with the United States Agency for International Development's (USAID) Social Marketing Plus for Diarrheal Disease Control: Point-of-Use Water Disinfection and Zinc Treatment (POUZN) Project to report on the lessons learned from eight years of field experience implementing safe water projects in 20 countries (United States Agency for International Development [USAID], 2007). These safe water projects included POU treatment of water with chlorine solution, safe water storage, and hygiene and water use education.

The report emphasizes the importance of developing partnerships throughout household water treatment programming. “Partnerships are vital to the successful adoption of the safe water product at all levels” (USAID, 2007, p. xiii). These partnerships can strengthen political support, help to promote product demand and uptake, and assist in the product distribution. Product champions, like local health workers or community leaders can help promote the efficacy of HWT products and increase acceptance of the behavior change essential for product adoption. The POUZN Project also emphasized that relevant government agencies should be involved early in the safe water project process. Implementers should assess the regulatory requirements and “meet with the appropriate ministries that govern product registration and approval” (USAID, 2007, p. 21). Government endorsement of the HWT product can boost the user’s confidence in its efficacy, and product certification can increase HWT uptake (Ojomo et al., 2015; USAID, 2007).

Not only should multiple community actors be involved in the implementation of HWT products, but training should reach beyond the product to integrate broader sanitation, hygiene, and health education. The WHO and United Nations International Children’s Emergency Fund (UNICEF) recommend that HWTS training should be comprehensive and include other environmental health interventions for holistic understanding and greater uptake. HWT interventions should not only cover maintenance and upkeep of the product, but also address handwashing at critical times, safe water storage practices, hygienic food handling, food and nutrition, reducing air pollution, and sanitary treatment of waste (World

Health Organization & United Nations International Children's Emergency Fund [WHO/UNICEF], 2012).

Defining HWT Adoption

Once an organization distributes a technology and teaches the beneficiary how to use and maintain it, it is important to evaluate whether the technology has been adopted appropriately and if use of the technology is sustained. In response to conducting a comprehensive literary review on what factors affect sustained adoption of WASH technologies in 44 studies, Hulland et al. (2015) determined that "'sustained adoption' is a highly variable term with different applications, depending on each implementing group's background and interests" (p. 77). They found that sustained adoption of a technology is oftentimes not clearly defined in research studies because it is difficult to measure, and few researchers actually define how they measure sustained adoption in the first place. Ultimately, "[t]here is no clear definition for sustained adoption employed in WASH literature, and sustained adoption is measured through self-report, observed practice, functionality and recalled knowledge" (Hulland et al., 2015, p. 2).

There are varying definitions of "sustained use" of a WASH technology in related literature. Hulland et al. found that 21 of the 44 reviewed studies defined sustained use as the continued use of the technology at least six months after the end of the project period, which is the time in which there is "external support to community groups, leaders and volunteers in the form of training supervision and feedback, distribution of technology, or provision of communication materials" (Hulland et al., 2015, p. 1). The most influential factors of sustained use were identified as regular, personal contact with a health promoter and personal follow up accompanied by group meetings or mass media advertisements to foster accountability.

From their review of literature, Hulland et al. conclude that there should be no standardized definition of successful or sustained adoption, but rather effort should be channeled to discuss and disseminate the various behavioral factors involved in the planning, distribution, and evaluation of WASH interventions (2015). The research team advises that the sustainability of a program and WASH adoption need to be clearly defined and measured both during the initial intervention and over time to ensure sustained use and practice. Additionally, routine monitoring and evaluation is essential in evaluating long-term behavior change.

Ultimately, the definition of successful and sustained adoption of HWT products are variable, so this research study assesses what indicators of successful adoption do organizations look for in their implementation of hollow fiber membrane filter programming. Additionally, this study evaluates how an organization's sensitivity to differing factors of adoption relate to how they define successful adoption. The following chapter discusses the methodology used to gather and evaluate these data.

Chapter 3: Research Methodology

This is a mixed methods study which involved both quantitative and qualitative data collection and analysis. The following sections discuss the research plan, specify the data collection process, and explain how the methodology was carried out.

Survey Development

The survey for this research served as the instrument for collecting data on the strategies organizations are using to distribute HFM filters. These include what resources and support they offer filter beneficiaries and insights on how they define successful filter adoption. The survey questions and responses were developed based on knowledge gained from relevant literature and from my own knowledge of HFM implementation. Particularly influential literature included WHO/UNICEF (2012), Hulland et al. (2015), Ojomo et al. (2015), and Daniel et al. (2018).

Questions from the survey fell into one of three categories: "contextual" questions, "factors of adoption" questions, and "success" questions. Contextual questions were intended to collect data on the type of program, context of implementation, type of filters distributed, and program impact. Factors of adoption questions, on the other hand, were designed to quantify the organization's responsiveness or sensitivity to enablers of filter adoption. The responses to these questions fell under one of the following five categories, or "adoption domains": (1) User Preferences, (2) Integration and Collaboration, (3) Government Influence, (4) Resources and Communication, and (5) User Training. These five categories were modified from the six domains established by Ojomo et al. (2015) to be more applicable to the context and scope of this research (refer to Chapter 2, section “Classifying Factors of Adoption” for more information on this research study). For example, the content that informed the User Preferences and Integration and Collaboration domains is well aligned to that of Ojomo et al.’s domains of the same name. Although the Government Influence domain has been renamed from “Standards, certification, and regulations” for simplicity, this domain still focuses on instances where filter certification and government involvement can influence filter adoption. The Resources and Communication domain for this study is defined as the communication channels available to filter beneficiaries, the financial responsibility that beneficiaries incur in obtaining a filter, and the availability of locally sourcing components of the filtration system. This domain integrates components of Ojomo et al.’s “Resource availability” and “Market strategies” domains. The User Training domain, modified from Ojomo et al.’s “User guidance on HWTS products,” consists of factors like training resources provided for beneficiaries to influence uptake of the HFM filter and monitoring and evaluation practices like follow up visits or surveys. Explanations of how the survey responses were weighed and combined using the five domains is covered in the “Domain Weighing and Combining” section in this chapter. The last two questions of the survey, the success questions, were developed to quantify each organization’s definition of successful filter adoption and success of the program itself. Success indicators are based on self-reported evidence, observed practice, and recalled knowledge pertinent to HFM filters and were influenced by Hulland et al. (2015).

The survey was developed in Qualtrics, and question types include text entry, single-answer multiple choice, multiple-answer multiple choice, and matrix-style questions. Five-point Likert scale questions were used to gauge frequency and likelihood. Although an interview or open-answer survey would have allowed for more in-depth responses, this survey was constructed with limited choices so that direct comparisons could be made across organizations and the responses could be evaluated through the lens of the five adoption domains. Some questions have an “Other” option where respondents were able to expand on a response, which provided opportunities for the organization to respond in a way that I did not predict. Overall, the survey questions were framed to understand how each participating organization conducts its filter distributions, rather than asking for the opinion of the individual representing the organization. The complete survey used for this study can be found in Appendix A.

The Institutional Review Board (IRB) at Appalachian State University determined that this research study was exempt from review because it did not constitute human subjects research. The target group of the study was organizations, not individuals, and all personal or organizational identifiers have been removed to preserve anonymity.

Study Participants

This study focuses on the techniques and processes applied by organizations that distribute HFM filters. Because of the prominence and widespread use of the Sawyer filter in developmental aid and emergency relief efforts, the 43 charity organizations that partner with Sawyer International were identified as the population from which the sample of participants was drawn. These organizations were selected because they represent organizations that have established HFM filter distribution programs. Two organizations not on Sawyer’s partner list were also surveyed because they are sister organizations to two of the partners and they fit the requirement of having a program focused on HFM filter distribution to households. The “Organizations of Interest” list included a total of 45 nonprofit organizations.

All organizations listed on Sawyer International's partner list have or are currently in the process of distributing Sawyer water filter products specifically to households in low-income countries. However, some of the organizations that responded to my initial inquiry have transitioned to use other HFM filters, like the Uzima and Village Water filters. These filters are similar to the Sawyer filters in design and function, but the differences in the products are highlighted and can be found in the Chapter 2 section titled "Hollow Fiber Membrane Filters." Because the planning and processes for filter distributions are still relevant to these few cases, these organizations were also asked to complete the survey for their programs. As a result, the survey question asking which type of HFM product was distributed during the program was expanded to include an "Other HFM filters" response for non-Sawyer distributors.

Recipients of the survey, from now on termed "representatives," were required to be a member of the organization of interest and knowledgeable about their filter distribution program(s). Representatives' titles included organization founder, board member, program director or leader, and operations staff. All representatives who received a survey voiced consent to participate in the survey and were informed that they could withdraw from the survey at any time.

Data Collection

The data collection process involved gathering general organizational and contact information, contacting the organization of interest and setting up a phone or video meeting with a representative, choosing a program based on specific criteria, and asking the representative to fill out the survey on the selected program. The following sections explain this process.

Initial Inquiry

During the initial inquiry phase, contact information was gathered from each organization's website, social media, and other internet sites. Other general information was recorded in Microsoft Excel, such as current / past programs and outreach efforts, program locations, impact, and organization headquarters contact and location. Depending on what information was available, an email or phone inquiry was initiated to get in contact with the organization's representative with the goal to set up a phone or video conversation. Of the total 45 organizations that were on the Organizations of Interest list, seven were not contacted because they either no longer have active websites, did not have contact information, or they did not mention water filtration projects. Overall, 38 organizations were contacted at least twice by phone or email, and 26 of those had a representative who was responsive and willing to have a phone or video conversation. All 26 organizations have headquarters based in the United States, but some representatives were based in the field at the time of the phone conversations.

Phone Conversations

Phone conversations (and video conversations, if requested) were initiated and set up with representatives of the 26 organizations between October 15th and December 18th, 2020. The purpose of each meeting was to introduce the research study to the representative and ask questions to determine which program should be the target of the survey. The conversation was semi-structured, and the following questions were used as a guide:

1. Do you have any programs where you distribute hollow fiber membrane filters specifically to households or families? If so, are they ongoing? If not, when were they carried out?

2. In what regions, countries, or areas are your programs located?
3. Does filter training differ depending on the area where they are distributed?
4. Has Covid-19 changed your response or program goals?

The primary requirement for an organization's program to be the subject of the survey was that the program be focused on the distribution of HFM filters to households. However, some organizations have multiple programs that fit this requirement, so an organization was selected if it has an ongoing HFM distribution program or recently implemented one. Another factor that impacted program selection was whether it is based in an East or Central African or Central American country, in an effort to be able to draw regional comparisons between different organizations' programs. If their selected program distributed both at the community and household levels, representatives were asked to complete their survey specifically according to the household distributions. They were also asked to report on their typical distribution tactics prior to the impact that Covid-19 may have had on their programming. The representatives were asked to accurately respond on behalf of their affiliated organization, regardless of their individual opinions or beliefs.

It is important to note that each representative of an organization was asked to complete the survey for *one* of their programs. Therefore, the program selected for the survey does not necessarily encompass the entire scope or impact of the interviewed organizations. The following sections will discuss the survey responses in terms of the "organization" as the identifier and not the individual respondent or the program because, the organization is ultimately the entity that is conducting and overseeing the program.

Deployment of the Survey

Two of the 26 organizations that participated in either a phone or video conversation were not asked to complete the survey. One organization was not issued the survey because it is involved only in the fundraising and not the direct distribution of filters, and another organization was not given the survey because its Sawyer filter distribution program is not yet underway. A total of 24 surveys were deployed via email, and 23 were completed, for a response rate of 96%.

Data Analysis

All survey responses were exported from Qualtrics into Microsoft Excel. Representatives' identifying information was limited to email addresses in case they needed to be contacted for response clarification. Survey responses were randomly assigned a number 1 through 23 so that they could be referenced anonymously in this study.

The survey export was adapted for analysis of the data. Information gathered from the phone conversations about the programs was added to the survey responses. This included the country or region where the programs were carried out and the timeframe within which the programs were conducted. Some Qualtrics questions with multiple responses were comma separated by default in the export, so each response was assigned its own column to prepare for easier analysis.

Domain Weighing and Combining

The responses to the "factors of adoption" survey questions were evaluated and weighted according to each domain represented in the response. Not all responses to a question belonged to the same domain, because some questions were structured to gather information across multiple domains. In addition, all questions with "Other" blanks, where representatives could input additional information, were not weighed in an effort to evaluate all organizations equally. The only exception to this was an “Other” response to Question 19, where Organization 11 indicated that it conducts filter training facilitated by Sawyer representatives. Because I instructed the survey recipient to indicate Sawyer’s role in the training and the fact that it is an alternative form of group training, this response was included in the domain calculation process. The following section walks through the survey questions and explains how they were weighed, if applicable. After the responses were weighed, the values that each organization received for each of their responses were combined for a total score in each of the five domains: User Preferences (UP), Integration and Collaboration (I&C), Government Influence (GI), Resources and Communication (R&C), and User Training (UT).

Weighing Survey Responses. Questions 1 through 5 of the survey gathered contextual data, and therefore, were not included in the domain calculation. The first survey question identified the program type: (1) emergency relief, (2) established program with permanent local staff, (3) temporary program with local partners, or (4) other. Question 2 asked which type(s) of HFM filter the organization distributes in their program. The answer options included four Sawyer filter system types and one open-answer response for programs that distributed other HFM filters, such as the Uzima UZ-1 filter or the Village Water Filter VF100. Questions 3 and 4 quantified approximately how many filters have been distributed and how many people have been impacted over the life of the program. Question 5 was a Likert-style question on whether the households served by the filter program range from predominately urban to predominantly rural.

Question 6 asked how often the distributing organization considers the following traits of the filter beneficiaries before it introduces the filter technology to them: (1) spiritual or religious beliefs, (2) cultural norms, (3) gender, (4) socio-economic status, (5) perception of the need to treat water in the first place, and (6) knowledge of or prior exposure to filter technology. The level of the organization's consideration of these six beneficiary traits falls under the User Preferences (UP) domain, which is supported by the research of Ojomo et al. (2015). Representatives indicated their organization's response on a five-point Likert scale from Always to Never. The response "Never" was assigned 0 points, because no consideration of a trait translates to no support of the UP domain. Therefore, a response of "Always" is 4 points, "Often" is 3 points, "Sometimes" is 2 points, "Seldom" is 1 point, and "Never" is 0 points.

Question 7 asked how the organization determines who is eligible to receive a filter. For the same reasons that "Other" responses were omitted from weighing, this open-answer question was not included in the domain calculations because of its qualitative nature.

Question 8 asked what is the most common financial impact on beneficiaries who receive filters. Responses were split into two categories: free of charge to the beneficiary; or requiring some sort of payment, trade of labor, or buy-in from the beneficiary. Literature shows that providing HWTS for free can hinder product adoption because of the lack of investment by users (Blanton et al., 2014; Ojomo et al., 2015). Therefore, a response that indicated an investment by filter beneficiaries was assigned 2 points, and a response that filters are free of charge was assigned no points. Two organizations indicated that the filters are free *and* there is a buy-in requirement. Therefore, they were assigned a score of 1 because they require investment from the beneficiary, even though the filter is free of charge. All organizations scored either 0, 1, or 2 on this question, and all responses belong to the Resource and Communication (R&C) domain.

Responses to the next two questions on the survey fell under the UP domain. Question 9 inquired whether beneficiaries have an option of choosing a water treatment product other than the HFM filter. Access to HWT choices promotes self-efficacy, so higher UP points were assigned to greater opportunity of choice. Accordingly, the response "Yes" was assigned 2 points, "Sometimes" was 1 point, and "No" was 0 points. Question 10 asked what beneficiaries most commonly report liking about the HFM filters. On one level, this question evaluates which filter characteristics are attractive to beneficiaries. On the other hand, it assesses whether distributing organizations ask users what they like about the product and if they are in tune with users' product assessments. No points were assigned if an organization selected "Our organization does not collect this information." If an organization indicated that it collects beneficiaries' preferences by choosing any of the other responses, 1 point was assigned. No matter how many responses were selected, an organization either does or does not collect information on users' preferences. Therefore, organizations could only receive 0 or 1 point on Question 10 for UP.

Question 11 asked if beneficiaries have a way to communicate filter breakage or issues to the organization, and all responses fell under the R&C domain. The four possible affirmative responses which specify the method of contact available to beneficiaries include: (1) in-person contact with local staff, (2) electronic communication such as email, (3) the organization's website, and (4) local partnering people/organizations. Each method of contact provides opportunity for filter users to ask for help, so each of these four affirmative responses received 1 point each, and points accumulated to reflect how many channels of communication are available. A “No” response was assigned 0 points. Therefore, organizations could receive up to 4 points for R&C.

Using a Likert scale response, Question 12 inquired how often beneficiaries reach out for assistance. The frequency of contact from filter users could indicate a range of possibilities: for instance, few responses from beneficiaries could mean that they have no problems with their filters, or it could mean that they are inhibited from communicating complications. Therefore, these responses were not weighed and simply provided context.

Question 13 was a matrix-style question that evaluated whether the organization collaborates with any of the listed persons/organizations during the three phases of Program Planning, Filter Intervention, and Monitoring and Evaluation. Collaborative partners’ options could include (1) community leaders, (2) teachers/healthcare workers, (3) local charity organizations, or (4) local government officials (the “Other” option was omitted from the scoring process). The first three partners were assigned to the Integration and Collaboration (I&C) domain because they indicate collaboration with community actors. However, the “local government” response fell under the Government Influence (GI) domain because of the specific and more nuanced influence government officials have on filter adoption. A point was assigned for selecting any of the collaborative partners in any of the three phases, yielding up to 9 points for I&C and 3 points for GI.

Question 14 asked the frequency at which the organization assesses whether the HFM meets local government standards and regulations as a water treatment product. Responses of “Always,” “Often,” “Sometimes,” “Seldom,” and “Never” were assigned 4, 3, 2, 1, and 0 points respectively. Because this question is directly associated with government influence and certification, it fell under the GI domain.

Question 15 and sub-question 15.1 assessed the local availability of HFM system components, which fell under the R&C domain. Question 15 used a five-point Likert scale response to assess the likelihood that beneficiaries are able to find replacements for broken filter system parts locally, ranging from “Extremely unlikely” to “Extremely likely.” Because all responses on the Likert scale were assumed to have equal intervals, they were assigned a number between 1 through 5, with 5 being “Extremely likely.” Question 15.1 similarly asked whether the buckets for bucket adapter systems are sourced locally (all distributors of Sawyer filters used bucket adapted filters in their programs, and the Uzima and Village Water filters are bucket-compatible). The Likert scale responses “Always,” “Often,” “Sometimes,” “Seldom,” and “Never” were scored as 4, 3, 2, 1, and 0, respectively.

Question 16 asked what supplemental materials or services the organization provides for beneficiaries and had four weighed responses (the “Other” option was omitted from the scoring process). Three of the responses fell under the User Preferences domain: “Pamphlet or other reading materials about the filter,” “Video instructions or demonstration on filter use,” and “Phone application.” The fourth response, “Water-council or support group to encourage filter use,” was a component of the I&C domain because it is a product of leveraging local support systems and influence. Each response was assigned 1 point, accumulating for a maximum of 3 points for UP and 1 point for I&C.

Question 17 asked what methods the organization uses to show beneficiaries that the HFM filter is effective at improving water quality. Each response was assigned 1 point and fell under one of four domains: two responses to the UT (User Training) domain because they are dependent on monitoring and evaluation efforts (“Anecdote of improved health associated with using filter” and “Statistics of improved health from using filter”); two to the

UP domain, because they speak to the specific preferences and desires of the filter beneficiary ("Demonstration that the filter reduces turbidity, or cloudiness of the water" and "Reported satisfaction with filter"); one to the GI domain ("Certification of the filter as an effective water treatment product"); and one to the I&C domain ("Approval by local leaders or peers"). Because points could accumulate, the maximum points were 2 points for the UT and UP domains and 1 point for the GI and I&C domains.

Question 18 asked the organization to indicate which, if any, of the following environmental health topics are covered during filter training. The possible responses were adapted from the WHO/UNICEF (2012) resource that evaluates an individual's knowledge of other environmental health interventions. The responses to Question 18 fell under three different domains. The responses "Safe storage practices" and "How to clean and maintain filter parts" were in the UT domain because they directly relate to training on water treatment. The responses "Handwashing at critical times," "Hygienic handling of foods," "Sanitation and treatment of waste," "Food and nutrition," and "Reducing household air pollution" were in the I&C domain because they are practices not directly related to water treatment but they supplement WASH training and promote improved health. The response "How to source new parts if any are damaged or lost" fell under the R&C domain. Each response was assigned 1 point for a maximum of 5 points for I&C, 2 points for UT, and 1 point for R&C.

The responses to Questions 19 and 20 fell under the UT domain. Question 19 asked the context in which beneficiaries are trained on how to use the filter. Two possible responses pertained to group training (either by organization's staff/volunteers or by community leader), so if either or both responses were selected, 1 point was assigned. (Note that this is the only instance where an "Other" response was included in the domain calculation. Organization 11 indicated that a Sawyer representative leads group training, so this response was retroactively given one point for the UT domain as if it were one of the other "group training" responses.) One point was given to the response "Private training in beneficiary's home," and similarly, 1 point was assigned if respondents checked "Mass media advertisement of public events." Points accumulated to a maximum of 3 for the UT domain.

Question 20 asked which methods of Monitoring and Evaluation (M&E) the organization utilizes. Respondents could select multiple responses from the following: "Baseline survey assessment," "Follow-up survey or visit," "Second-follow up," "Third follow-up," and "We do not conduct Monitoring and Evaluation." Each affirmative response of M&E action was assigned 1 point, and the response that no M&E was conducted received 0 points. Therefore, the points accumulated for a maximum of 4 points for the UT domain. Question 21 followed up on Question 20 by asking when the aforementioned follow-ups are conducted, referencing the time since the filter distribution. This question provided contextual data only, and its responses were not weighed.

The last two survey questions evaluated how each organization defines successful adoption and how the organization rates its program's success. These questions were not included in the domain weighing and calculations. Question 21 asked what indicators the organization looks for to determine whether filters have been successfully adopted. The possible indicators from which respondents could select were as follows:

a) Demonstration of correct filter use by beneficiary during the intervention
b) Local health records indicating improved health
c) Self-reported evidence of improved health (via survey, interview, etc.)
d) Demonstration of correct filter use by beneficiary in follow-up visit
e) Confirmation that filter is present in beneficiary's home in follow up visit
f) Water quality testing in follow up visit

g) Reported satisfaction with filter product
h) Increase in demand for filters
i) Other: ________

The final question on the survey, Question 22, asked "According to your organization, how successful was filter adoption in this program?" The five-point Likert responses ranged from "Not at all successful" to "Extremely successful." Though this question is quite subjective in nature, it was intentionally positioned after Question 21 so that respondents would be thinking how successfully filters were adopted in consideration of the indicators they selected in Question 21.

Combining of Domain Scores. To evaluate each organization's sensitivity to the five domains of filter adoption, all weighed "factors of adoption" responses were combined to compute five domain scores for each organization. The maximum points for the User Preferences (UP), Integration and Collaboration (I&C), Resources and Communication (R&C), User Training (UT), and Government Influence (GI) domains were 32, 16, 16, 11, and 8, respectively. Because some domains had more associated questions and responses than others, each organization's totaled point score in a domain was normalized by dividing by the maximum number of points possible for that domain and multiplying by 100. As a result, each category ranges from 0 to 100, and an organization's resulting score in a domain is a percent of the total points for that domain. Higher sensitivity to a domain is represented by a score closer to 100, and lower sensitivity to a domain is represented by a score closer to zero.

Statistical Analysis with t-tests

Each organization's score in each of the five domains was evaluated against the indicators of successful adoption that they selected to determine if there is a relationship between adoption domain sensitivity and defining successful filter adoption. Two-Sample *t*-tests were used as the tool to evaluate the relationships between the mean domain scores of organizations that selected a specific success indicator and those that did not select that indicator.

Two-Sample *t*-tests are hypothesis tests that assess whether two population means are different. Question 21 asked which indicators the organization looks for to determine whether filters have been successfully adopted. Survey participants could select from as many of the eight indicators deemed applicable to their organization. Therefore, the resulting data from this question were binary: an organization either does ("Yes") or does not ("No") consider an adoption indicator. Welch's *t*-tests assuming unequal variance were used to evaluate the relationship between the mean score of organizations that selected a success indicator ("Yes" group) with the mean score of those that did not ("No" group).

The significance level was set to .05. At this significance level, the null hypothesis can be rejected if the *p*-value is less than .05. The null hypothesis (H_O) is that there is no difference between the means of the two groups, or that the means of the two groups are equal (Equation 1). The alternative hypothesis (H_a) is that there is a difference between the means of the two groups, or that the means of the two groups are not equal (Equation 2). Because this was exploratory research, and there was not enough information to predict whether the mean of the "Yes" group would be greater than or less than the mean of the "No" group, a two-tailed test was used to detect the effect in both directions, and the alternative hypothesis was simply that there is an expected difference between the means.

$$H_O: \mu_1 = \mu_2 \tag{1}$$

$$H_a: \mu_1 \neq \mu_2 \tag{2}$$

Thirty-five *t*-tests were conducted using Excel, one for each combination of the five adoption domain scores and the seven testable success indicators. Only one organization wrote in an "Other" response, and the response "Water quality testing in follow up visit" was selected by only one organization, so there were not enough responses in the "Yes" group of these two indicators to conduct *t*-tests. The results of the thirty-five *t*-tests are found in the Chapter 4 section "Results of *t*-tests."

Chapter 4: Results and Analysis

This chapter reports the descriptive results from the survey instrument, the weighing and combining of the adoption domains, and the statistical analysis between the adoption domains and the success indicators. The purpose of this study was to evaluate the role of organizations that distribute selected HFM filters in household settings, so data collection targeted a specific program within each organization. Note that the following section will refer to the organizations as the identifier, though the survey responses are specific to only *one* of their potentially numerous programs. Therefore, the following results may not encompass the full extent or impact of the work of the surveyed organizations.

Program Context

Twenty-three organizations completed a survey for one of their HFM household distribution programs. Of these, 22 programs are located in 15 countries, and one program is located in a region comprised of three neighboring countries. Nine programs are located in the Caribbean or Central/South America, nine are located in the West or Equatorial regions of Africa, and five are located in South or Southeast Asia. At the time of data collection for this study (December 2020), all programs have operated within the timeframe of 2008 to 2020 for lengths of time ranging from two months to twelve years. Sixteen of the 23 organizations reported on programs that were current as of December 2020.

Survey Results: Descriptive Statistics

These descriptive statistics answer the first research sub-question, “What intervention methods do organizations that distribute hollow fiber membrane filters to households use?”

The corresponding survey question number is displayed in parentheses and the individual organizations are represented as “Org. #” for reference (see Appendix A for the complete survey).

Q1-Q5

The context of the organizations’ programs is sorted into one of three categories (Q1). Of the 23 organizations that were surveyed, 13 are established programs with permanent local staff, seven are temporary programs with local partners, two are emergency relief, and one self-identifies as a combination of temporary and emergency relief (Org. 20). Three organizations indicated “Other” (Orgs. 8, 9, and 11) on the survey, but their programs were manually placed in one of the three main categories based on their open-answer responses and my understanding of their program via phone conversations.

Because the sample population of organizations originated from Sawyer International’s charity partner list, the majority of organizations distribute Sawyer products (Q2). Twenty of the 23 organizations distribute the Sawyer Bucket Adapter system with PointONE™ filters. In addition to the PointONE™ filters, one organization distributes the bucket adapter system with Point ZeroTWO filters (Org. 1), and another distributes the Sawyer MINI filter (Org. 21). Three organizations distribute HFM products other than Sawyer for the programs surveyed. Org. 14 distributes the Uzima UZ-1 filter, and Orgs. 20 and 23 distribute Village Water filters (VF100). Org. 14 explained that they switched to Uzima products because the tabletop system is advantageous: the stacked buckets mean only one surface is required, the filter is protected within, and a safe storage option is guaranteed. Orgs. 20 and 23 said they distribute Village Water Filters because they are more cost effective than Sawyer filters.

Table 1 displays the organizations' ID (randomly generated), the number of filters distributed (Q3), and the approximate number of individuals impacted over the life of the program (Q4). The number of filters distributed by the organizations range from 40 to 125,000 filters. The impact ratio was calculated by dividing the number of people impacted by the number of filters distributed for each program. The impact ratio varies widely, with a mean of 16.75 and a standard deviation of 33.0, impacted by outliers like Orgs. 13 and 18. The majority of program distributions are focused in rural regions (Q5), with 12 of the organizations indicating that their programs serve "predominantly rural" households, nine indicating "more rural," and two indicating "equally urban and rural."

Table 1

Number of Filters Distributed and Impact by Organization

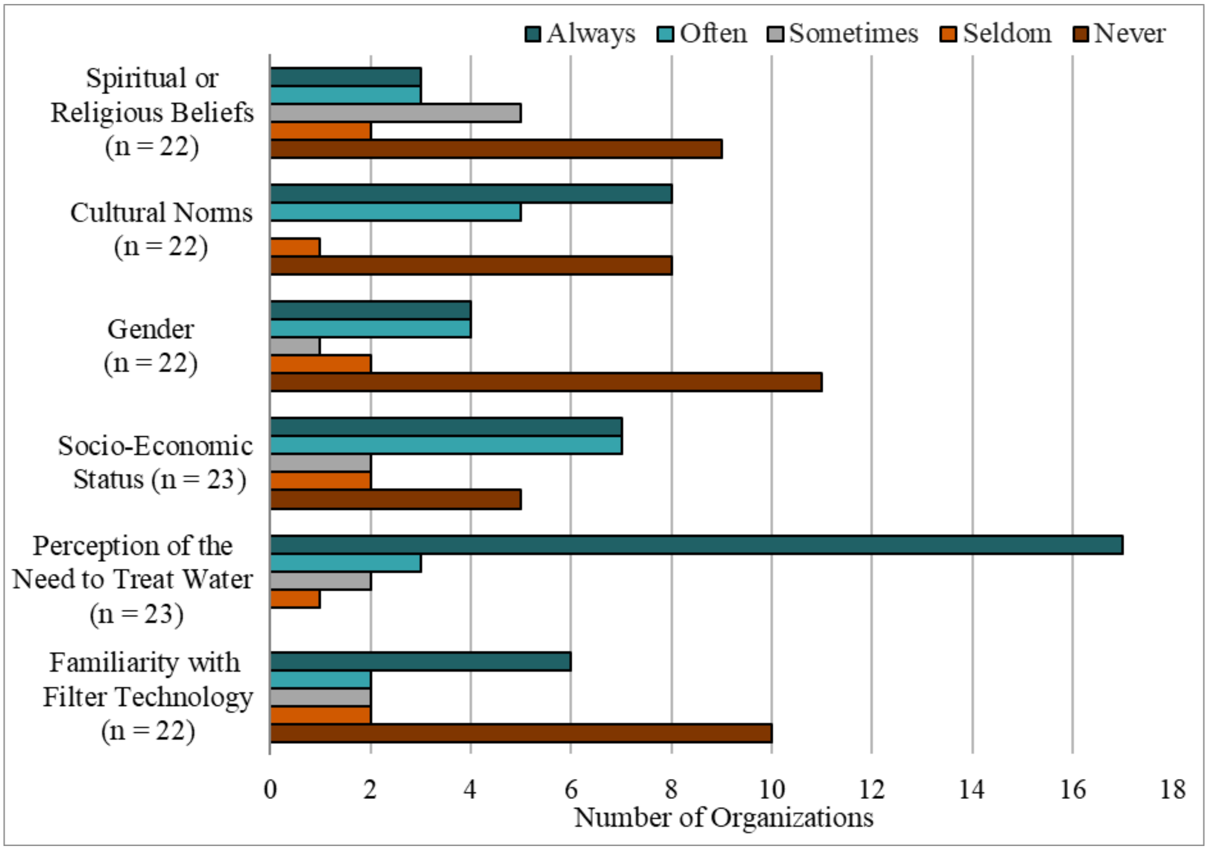
Org. ID	Filter Number	Impact Number	Impact Ratio
1	2,000	50,000	25
2	250	1,750	7
3	2,000	10,000	5
4	11,000	51,000	4.64
5	5,120	30,720	6
6	500	4,250	8.5
7	600	3,000	5
8	100,000	600,000	6
9	500	2,500	5
10	7,947	34,339	4.32
11	2,311	7,000	3.03
12	125,000	1,250,000	10
13	8,000	400,000	50
14	6,000	148,000	24.67
15	120	623	5.19
16	15,000	300,000	20
17	2,000	15,000	7.5
18	500	80,000	160
19	26,000	208,000	8
20	1,300	6,500	5
21	1,235	5,000	4.05
22	40	250	6.25
23	1,777	8,885	5

Q6

Question 6 of the survey asked how often six specific beneficiary traits are considered before the filters are introduced. Organizations indicated on a Likert scale the level of consideration of each trait, ranging from “Always” to “Never” (Figure 6). Org. 3 did not respond to “Spiritual or Religious Beliefs,” “Cultural Norms,” “Gender,” or “Familiarity with Filter Technology”, so the total number of responses is 22 for those four traits.

Figure 6

Organizations' Level of Consideration of Beneficiary Traits Before Filter Introduction



The results from Figure 6 shows that 16 of the 22 organizations are neutral or are not likely to consider the beneficiaries' spiritual or religious beliefs when introducing HFM filters. Thirteen of 22 organizations are likely to consider cultural norms that may affect whether a beneficiary adopts the filter. Gender is the trait that the highest number of organizations indicate they never consider, with only 36.4% indicating that they do consider the gender of an individual prior to giving them the filter. Socio-economic status is a trait that 14 of 23 organizations indicate that they are likely to consider, with the other 39.1% indicating neutral or negative likelihood. "Perception of the Need to Treat Water" has the highest absolute confirmation, with 74% indicating they "Always" consider this trait, 13% indicating they "Often" do, and two and one organizations indicating "Sometimes" and

"Seldom," respectively. The last trait on the chart, "Familiarity with Filter Technology," reveals that eight of 22 organizations selected a more affirmative likelihood of considering the trait. All traits apart from spiritual/religious beliefs are favored at the extremes ("Always" and "Never") of the Likert scale responses.

Q7-Q9

A variety of themes arise from the open-ended question that asked how organizations determine who is eligible to receive the filter (Q7), but a few dominant ones prevail. The theme that need is determined based on water quality is mentioned by 12 out of 23 organizations. Nine organizations say that they work with local partners to identify those in most need, and five mention that households with young children get priority. The requirements that potential beneficiaries participate in filter training and profess a commitment to sharing the filter with others are each stated by two organizations. In addition, one organization states that a requirement is that beneficiaries are willing to source a component of the filter system themselves. The presence of these themes in the responses were independently identified by a colleague and verified to provide interrater reliability.

When asked the financial impact of the filters on beneficiaries (Q8), 18 of 23 organizations respond that the filters are free of charge, three indicate that there is some sort of financial or buy-in investment required, and two organizations indicate that the filters are both free *and* there is a buy-in requirement. This means that the majority of surveyed organizations do not require investment from the beneficiary.

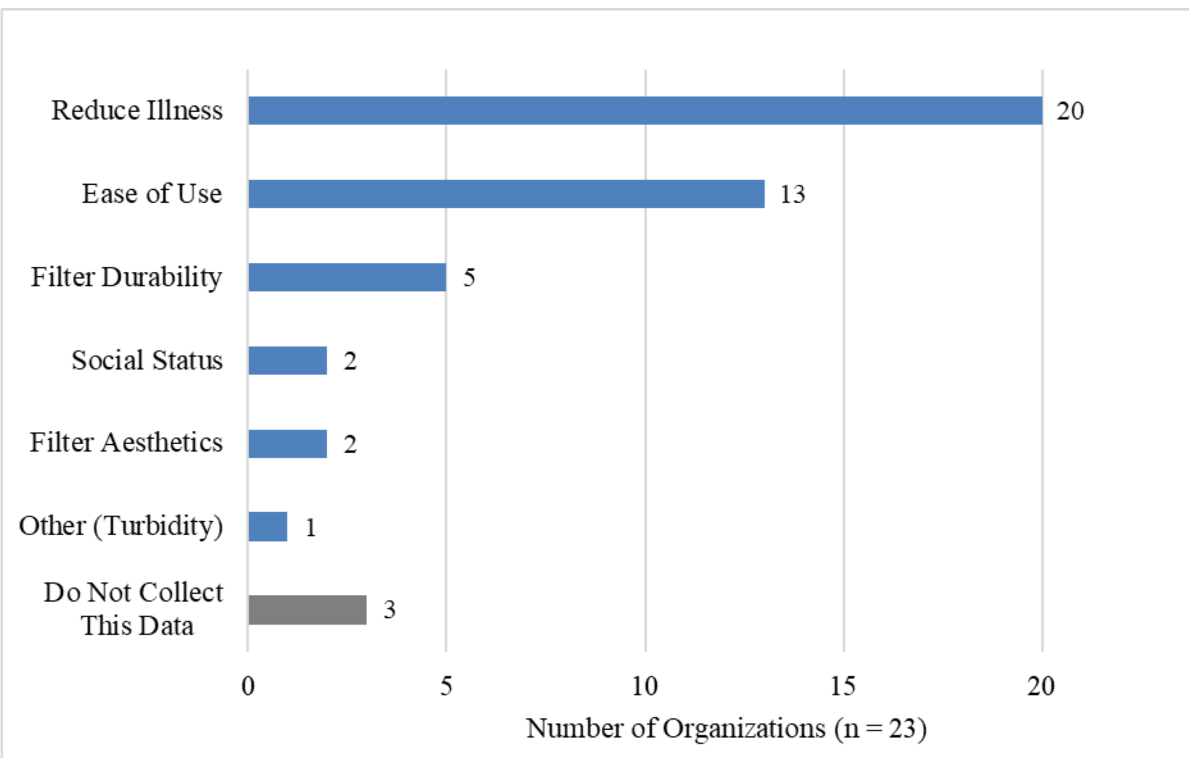
In regard to whether organizations give beneficiaries an option of choosing a water treatment other than the HFM filter (Q9), none indicate "Yes," three indicate "Sometimes," and 20 indicate "No." These results show that the vast majority of organizations do not give beneficiaries a choice in the water treatment product that they use.

Q10

Question 10 asked what beneficiaries most commonly report liking about the HFM filters. The responses are summarized in Figure 7. The majority of organizations say that reducing illness is most commonly referenced by beneficiaries (20 of 23), with ease of use as a second most popular response (13 of 23). Social status and filter aesthetics are only reported by two organizations each. One organization indicated in the open-answer "Other" response that the filter's ability to reduce turbidity was attractive to beneficiaries. Three organizations do not collect data on what beneficiaries like about the filters they distribute (Orgs. 3, 8, and 13).

Figure 7

What Beneficiaries Most Commonly Report Liking About HFM Filters

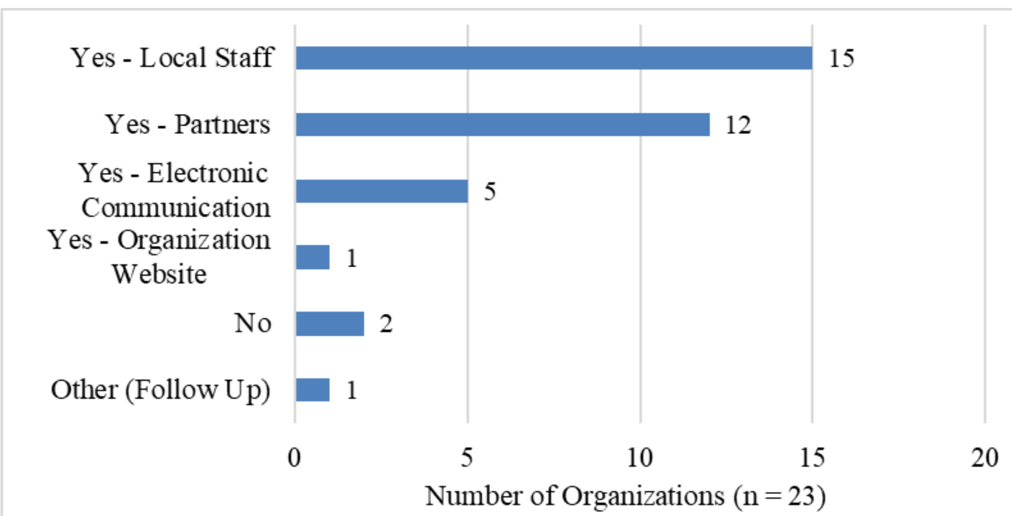


Q11 & Q12

Question 11 asked which channels of communication are accessible to beneficiaries so that they can report filter breakage or problems. As shown in Figure 8, 15 of the 23 organizations have local staff accessible for beneficiaries to communicate issues in person, 12 organizations indicate that beneficiaries can report issues to local partnering people or organizations, and five organizations say that beneficiaries can use electronic communication—like text messaging, cell phone application, or email—to report issues. One organization (Org. 23) responded that beneficiaries can use its website to report filter problems. Org. 6 responded “Other” and expanded by saying that they conduct three follow ups after the filter installation, which implies that this organization is accessible to beneficiaries during those follow ups.

Figure 8

Communication Availability and Channels for Beneficiaries to Report Filter Issues



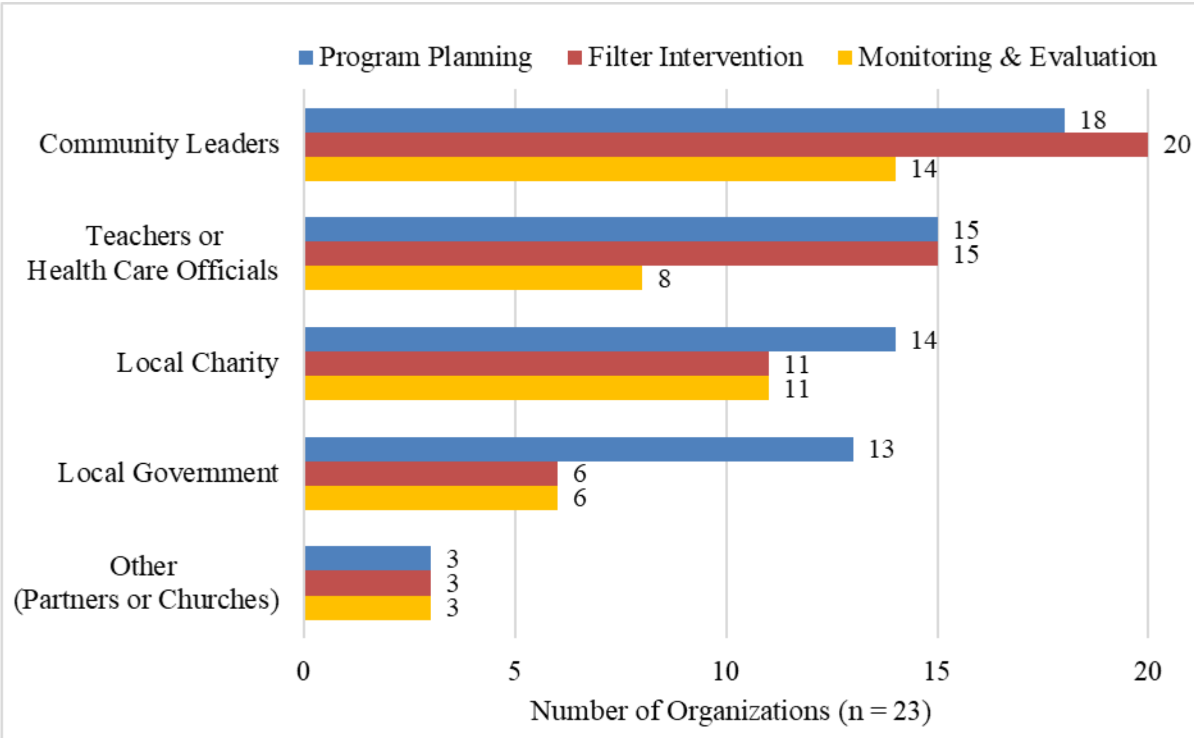
Organizations were asked “How often do beneficiaries reach out for assistance?” (Q12). Given that this question was asked just prior to asking what channels of communication are available to beneficiaries who need to report filter issues, respondents may have interpreted this question differently. This question yielded a variety of responses, with one organization responding “Often,” two responding “Sometimes,” 15 responding “Seldom,” one responding “Never,” and two responding that they “Don’t know.” These responses can be interpreted through the lens that, according to the majority of organizations, beneficiaries seldom reach out for assistance because they fully understand how the filtration system works, their training was comprehensive, or they have no filter issues. Another lens through which to interpret this dominant response is that the communication channels are not very accessible to beneficiaries, or that there are cultural or contextual barriers to asking for assistance.

Q13

Figure 9 illustrates with which type of organizations or persons the organizations collaborate over the three main phases of their programs: program planning, the filter intervention, and monitoring and evaluation (M&E) (Q13). Community leaders are the most involved parties during program planning and M&E, with 18 and 20 organizations indicating their collaboration in these respective phases.

Figure 9

Local Collaboration in the Three Phases of the HFM Filter Program



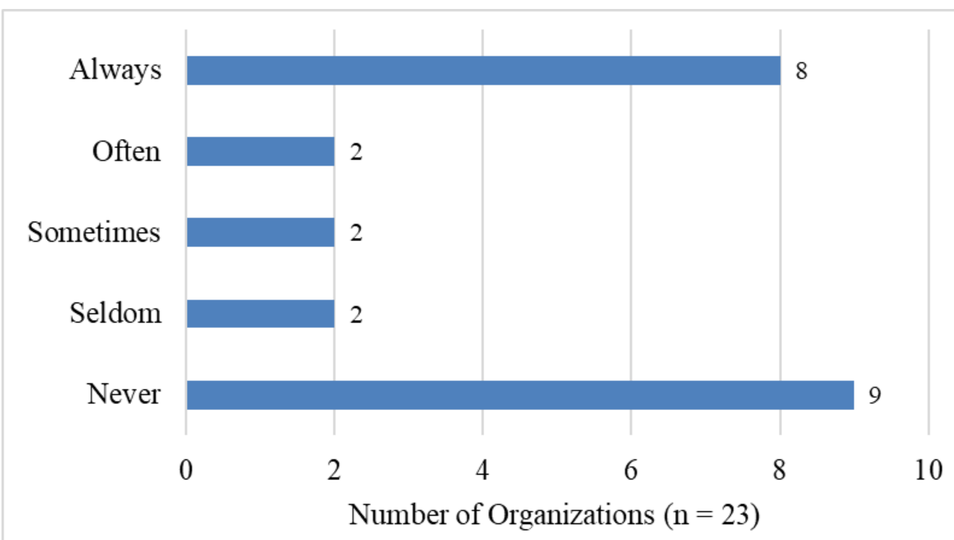
Overall, more collaboration partners are involved in the program planning phase (63 total responses) than the filter intervention (55 responses) and M&E phases (42 responses). Of all the partners listed, community leaders have the highest involvement across program phases (52 responses), with teachers/health care officials and local charities a close second (38 and 36 responses, respectively). Thirteen of the 23 organizations collaborate with local government in at least one of the program phases, with the majority of partnership happening in the planning phase. Three organizations filled the open-answer "Other" response with the words "local churches" (Orgs. 4 and 21) or "Partnerships" (Org. 13), and these "Other" groups are involved in all three phases of those organizations' programs.

Q14

When asked if the organization assesses whether the HFM filter meets local government standards and regulations as a water treatment product, responses are varied and heavily lean towards the extremes (Q14). The Likert scale responses for this question are Always, Often, Sometimes, Seldom, and Never. As shown in Figure 10, nine of the 23 organizations indicate that they "Never" assess whether their filters meet local government standards, while eight indicate that they "Always" make those assessments. The "Often," "Sometimes," and "Seldom" responses were chosen by two organizations each. This graphic shows that nearly the same percentage of organizations tend to research and evaluate local government standards for water treatment as those that do not.

Figure 10

Likelihood of Assessing Whether HFM Filter Meets Local Government Standards



Q15 & Q15.1

Questions 15 and 15.1 evaluate the likelihood of sourcing system parts locally. Figures 11 and 12 show the likelihood of beneficiaries sourcing broken filter parts locally (Q15) and the likelihood of sourcing the bucket for the filter system locally (Q15.1). In

Figure 11, 10 organization beneficiaries are extremely or somewhat likely to be able to locally source broken filter parts. On the other hand, eight organizations say that filter users are "Extremely unlikely" to find filter parts locally, while three indicate that they are "Somewhat unlikely." The variation in these responses is likely due to the difference in the availability of resources depending on the location of the beneficiaries' homes (rural versus urban), and access to local supply chains and distribution centers for the HFM filters themselves.

Figure 11

Likelihood of Sourcing Broken Filter System Parts Locally

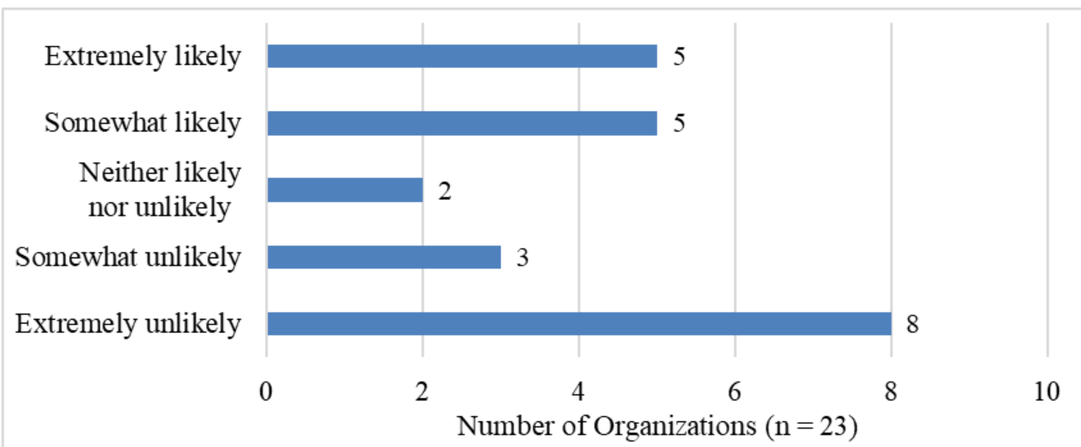
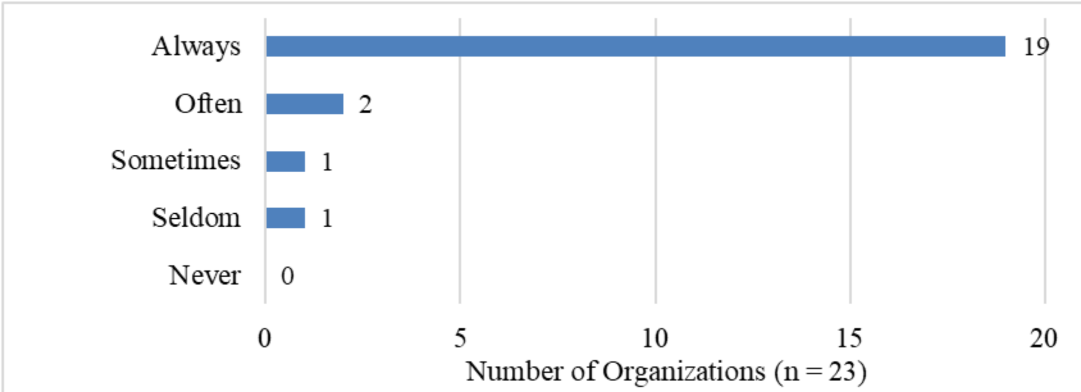


Figure 12 shows that 19 of 23 organizations confirm that the buckets for the filter systems are "Always" sourced locally, while two indicate "Often," one indicates "Sometimes" and "Seldom" each, and none select "Never." The bucket is a filter system component that is most likely to be sourced locally because it is common across cultures and serve multiple purposes.

Figure 12

Likelihood of Sourcing Buckets Locally

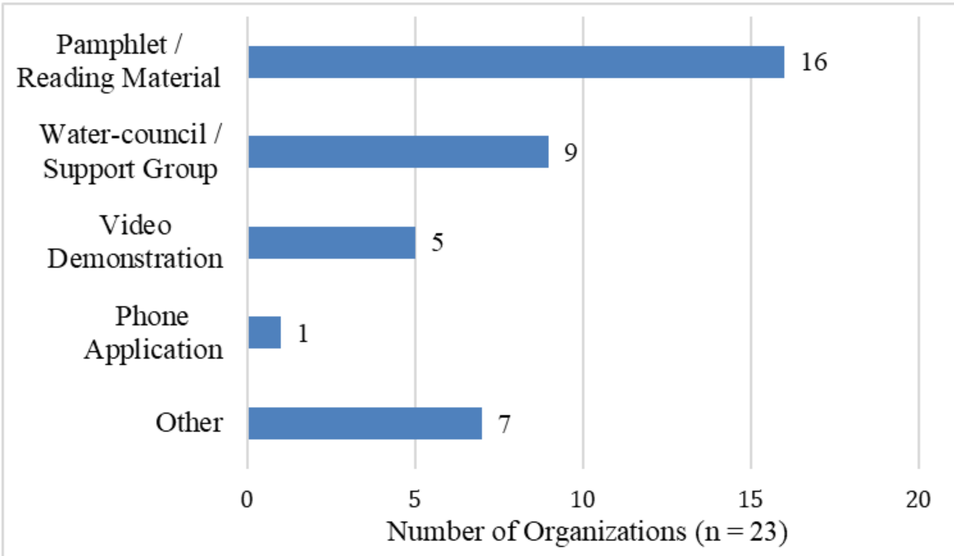


Q16

The purpose of Question 16 was to gather information on what type of supplemental materials or services apart from the filter that distributing organizations provide for the beneficiaries. Figure 13 reveals that 16 of the 23 organizations distribute some sort of pamphlet or reading material about the filter to facilitate understanding. Nine organizations assemble a water council or support group to help encourage filter use. Five say that they use a video to instruct or demonstrate how to use the filter, and only one says it uses a phone application. Seven of the organizations elaborated on their selection of the "Other" response, with mention of "training" (Orgs. 4 and 8), sticker instructions provided by Sawyer for the bucket (Org. 21), collaborative partners like a "medical clinic nurse" (Org. 2) or the "Ministry of Health" (Org. 10), and "follow up" (Org. 8 and 19).

Figure 13

Supplemental Materials or Services that Organizations Provide to Beneficiaries

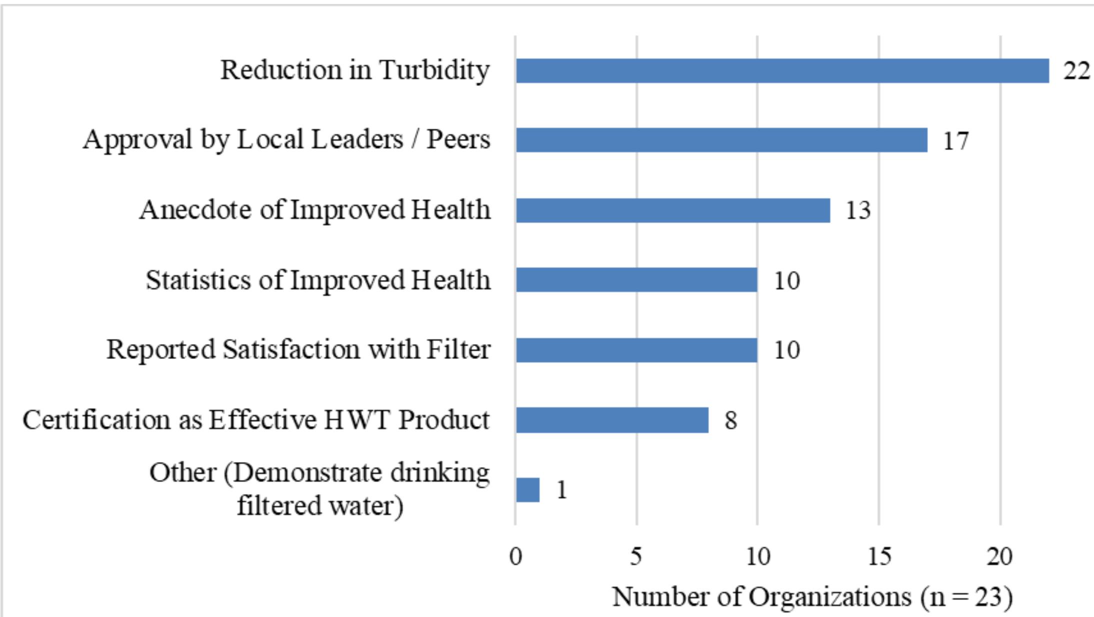


Q17

Question 17 evaluated what methods are most commonly used by organizations to persuade beneficiaries that the filters are effective as a water treatment product. As shown in Figure 14, all but one organization (Org. 2) indicate that reduction in turbidity is a method used to persuade filter adoption. Seventeen of the 23 organizations say that advertising approval of local leaders and peers is a method they use, and 13 refer to anecdotes of improved health when discussing the filter effectiveness. Ten organizations use statistics of improved health, and 10 also reference reported satisfaction with the filter to influence adoption by new beneficiaries. Eight organizations use certification of the filter to persuade beneficiaries that the product is effective. One organization elaborated on this response by indicating "Other" and saying that its filter certification by the WHO is important (Org. 20). Organization 21 indicated that an additional way that they persuade beneficiaries of the effectiveness of the filter is by a demonstration of filtering water into a clear glass and drinking it. These results show that emphasizing the visual difference between contaminated and filtered water is the most-used tactic to persuade filter effectiveness, but that social influence is also commonly leveraged.

Figure 14

Methods Used by Organizations to Persuade Beneficiaries of Filter Effectiveness



Q18

Question 18 asked what type of additional content is integrated into the filter training. Comprehensive environmental education is recommended during HWT training to encourage holistic understanding of WASH practices and behavior change (WHO/UNICEF, 2012). Figure 15 shows that all 23 organizations demonstrate how to clean and maintain the filter parts, which is critical for sustained use of the filter because of their design and tendency to clog with sediments. Twenty-one of the organizations include training on safe water storage practices. Safe storage goes hand-in-hand with water treatment because of the potential of re-contaminating the filtered water, especially if it is collected in a container and not used immediately. Eighteen of the organizations discuss handwashing with filter beneficiaries, and 13 instruct on the importance of hygienic food handling practices.

Only 52% of the surveyed organizations talk with beneficiaries about how to source replacement filter parts. These responses can be compared back to Figure 11, where 11 organizations say that beneficiaries are unlikely to find replacement filter system parts locally. Nonetheless, this means that half of the surveyed programs are distributing products that are likely to be rendered useless if a part breaks or is damaged.

Figure 15

Additional Topics Covered in Filter Training

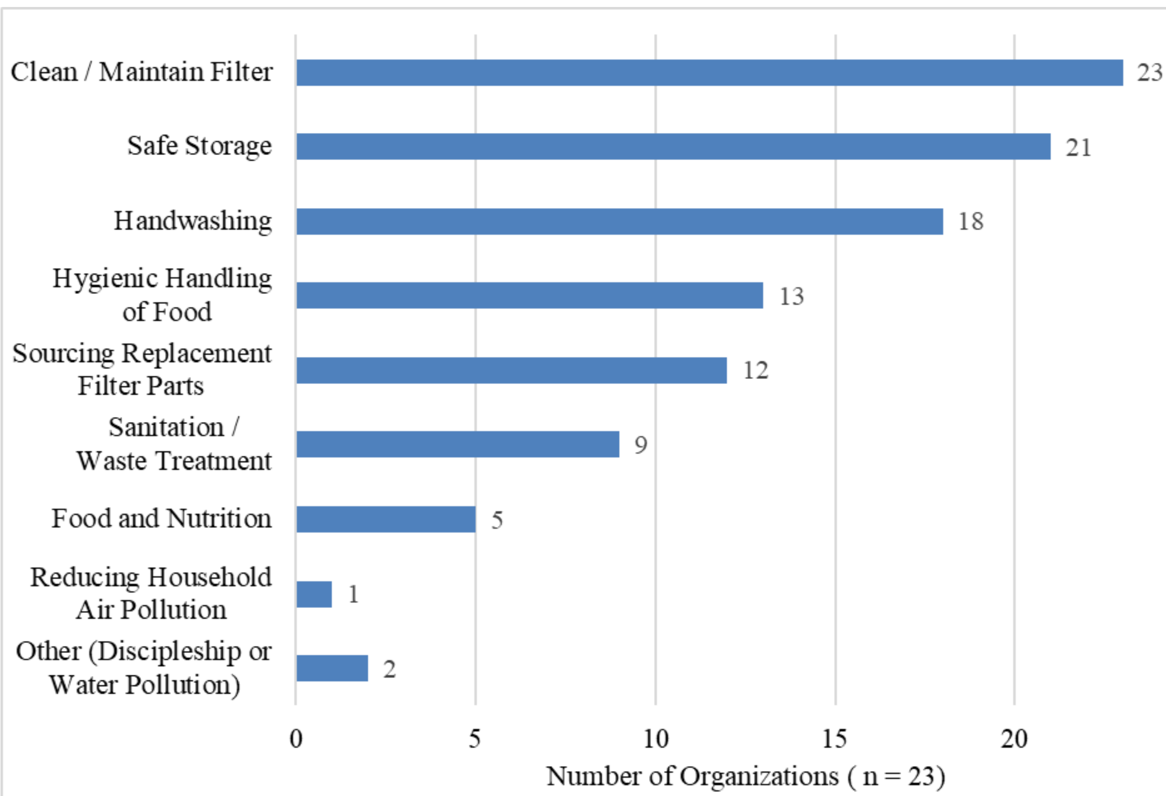


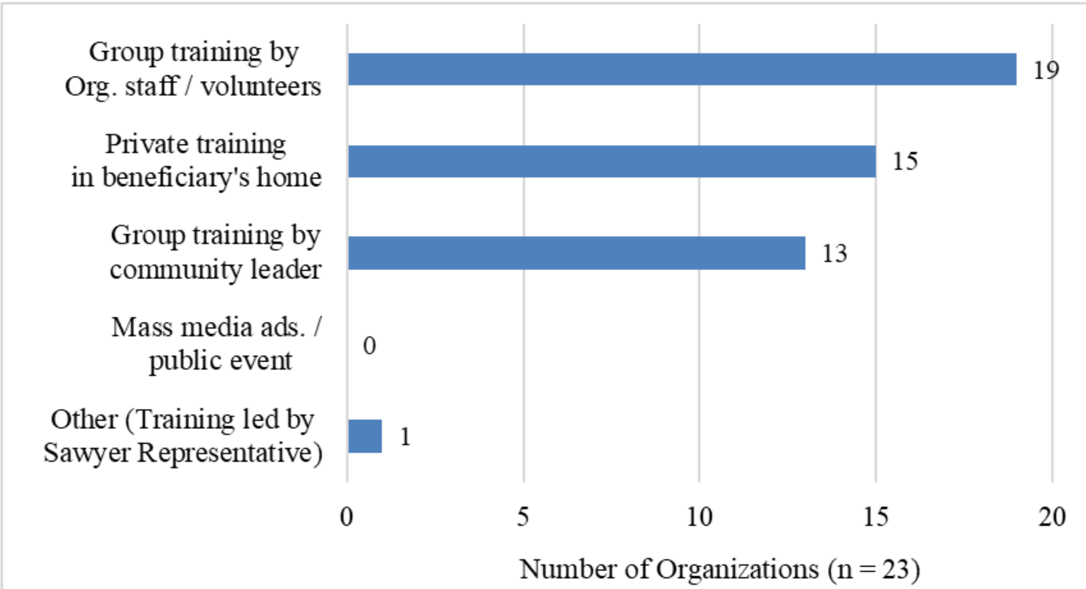
Figure 15 also reveals that sanitation and treatment of waste are topics covered by nine organizations, and food/nutrition are covered by five. One organization addresses issues of household air pollution (Org. 9). Two organizations indicated "Other" responses: "discipleship" (Org. 19) and "water pollution" (Org. 13).

Q19 & Q20

Question 19 asked about the context in which beneficiaries are trained on how to use the filter; the organizations' responses are shown in Figure 16. Nineteen of the 23 organizations hold group trainings facilitated by the organization's staff or affiliated volunteers. Thirteen organizations train in groups led by community leaders. Data from the survey show that 10 of these organizations conduct group training led by both the organization's staff/volunteers *and* community leaders. Another method of filter training commonly employed is done privately in the beneficiary's home, with 15 organizations indicating this response. Every organization that indicated that they conduct a private training in the home also conducts group training. No organizations use mass media outlets or public events to broadcast training. Org. 11 responded that a Sawyer representative leads their filter training, which is an alternative to the group training responses posed in this question.

Figure 16

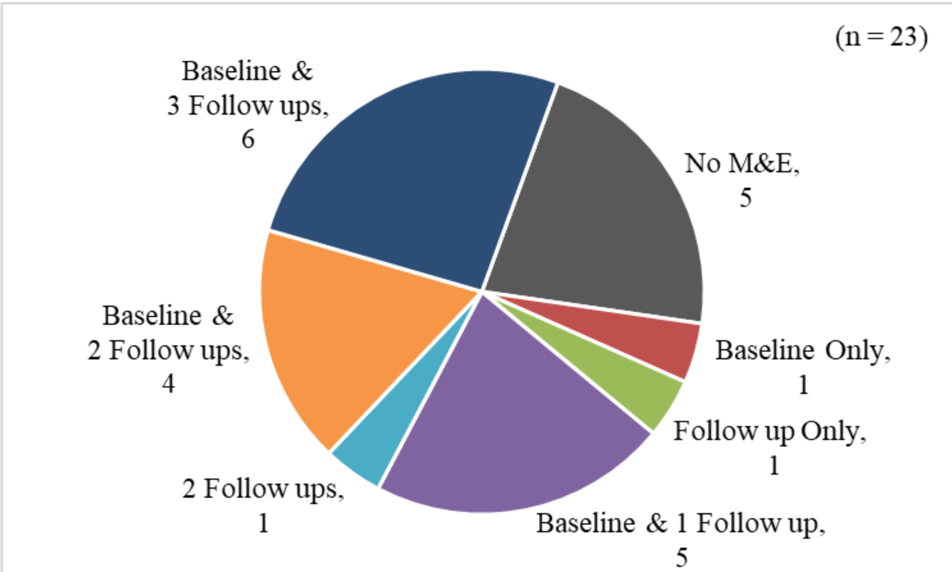
Context of Filter Training



Question 20 evaluated the extent of monitoring and evaluation (M&E) practices conducted by the distributing organizations for their surveyed program. The data reveal that the majority of organizations conduct at least one initial assessment during filter distribution and one follow up assessment. Out of the 23 organizations, 16 conduct baseline survey assessments, 17 conduct at least one follow up survey/visit, 11 conduct second follow up surveys/visits, 6 conduct third follow ups/visits, and 5 do no monitoring and evaluation. Figure 17 shows the combination of M&E practices, with one organization each conducting only a baseline assessment, only a single follow up, and two follow ups. Five organizations conduct both a baseline and a follow up, while four organizations conduct both a baseline and two follow ups. Six of 23 organizations conduct a baseline assessment and three follow ups.

Figure 17

Type of Monitoring and Evaluation Conducted by Distributing Organizations

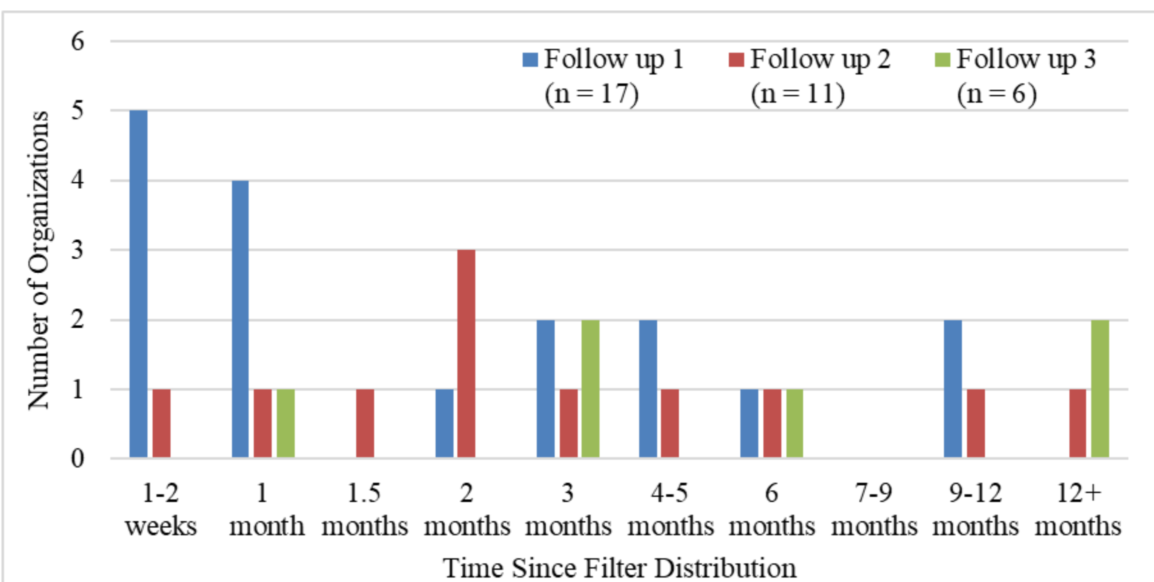


One may expect that programs described as established with local staff would be more likely to conduct baseline assessments and multiple follow ups compared to emergency response or temporary programs, because of the stability of human capital and resources. Of the 13 organizations that have "established programs" (refer to Q1), two do no M&E, two conduct only 1 follow up, four conduct only 2 follow ups, and five conduct 3 follow ups. Ten of the 13 organizations complete baseline assessments. In addition, the two organizations with emergency relief programs conduct no monitoring and evaluation. This shows that even though having an established program does not necessarily imply evidence of robust M&E practices, organizations with established programs are more likely to conduct multiple follow ups.

All the organizations that conduct some type of follow up assessment were asked to indicate the approximate time of the follow up since filter intervention (Q20.1). Figure 18 shows the approximate time that organizations conduct their first, second, and third follow ups (if applicable). Nine of the 17 organizations that conduct at least one follow up do so within a month of the filter intervention. The time of the second follow up is more spread over a year: out of 11 organizations, the median response is two months since filter intervention, though the range is from 1-2 weeks to 12+ months. Only six organizations indicate that they conduct a third follow up. The graph shows that third follow ups most commonly occur after three months or 12+ months. These data show that there is a lot of variation in the number of follow ups and when they are conducted. Sawyer recommends in its training resources that the first follow up should be conducted at two weeks, and a second follow up should be conducted at eight weeks to detect if behavior change has occurred (Sawyer, 2021). Village Water Filters does not mention follow up in its training resources for NGO distributors (Village Water Filters Inc., 2018a), and there are no M&E recommendations on Uzima's website.

Figure 18

Time of Organizations' Follow Ups Since Filter Intervention



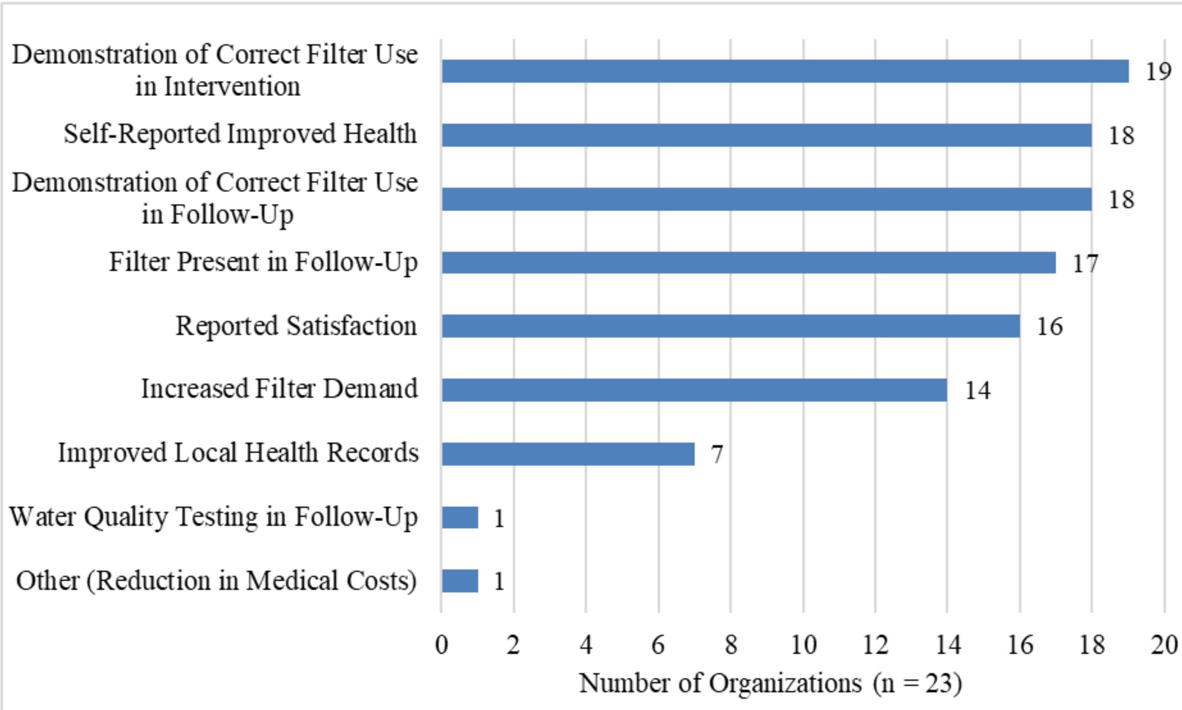
Though there is no comprehensive definition of sustained use, Hulland et al. (2015) found that research studies commonly evaluate whether use of a technology has been sustained at least six months after the end of the project period. By this definition, these data show that eight organizations have the potential to assess "sustained use" after filter implementation (Org. 14 conducts its second and third follow ups after six months).

Survey Results: Defining Successful Adoption (Q21 & Q22)

The last two questions on the survey targeted how organizations define successful filter adoption and the overall success of their program to answer the third research sub-question, "How do distributing organizations define and measure 'successful adoption' of hollow fiber membrane filters as household water treatment products?" Figure 19 shows that the most popular indicator of successful adoption that organizations use is demonstration of correct filter use during the intervention, with 19 of 23 organizations selecting this response. Both self-reported improved health and demonstration of correct filter use in a follow up visit are selected by 18 of the organizations. Seventeen organizations say that successful filter adoption is demonstrated by the filter being present during a follow up visit. Sixteen consider reported satisfaction as an indicator of successful adoption, and 14 interpret increased filter demand as a success indicator. Figure 19 also shows that seven of the 23 organizations consult local health records to quantify improved health, and only one organization conducts water quality testing in a follow up to define successful filter adoption. One organization indicated an "Other" response of calculating the reduction in hospital and medicine costs related to water-borne diseases after filter implementation to reflect successful adoption (Org. 14).

Figure 19

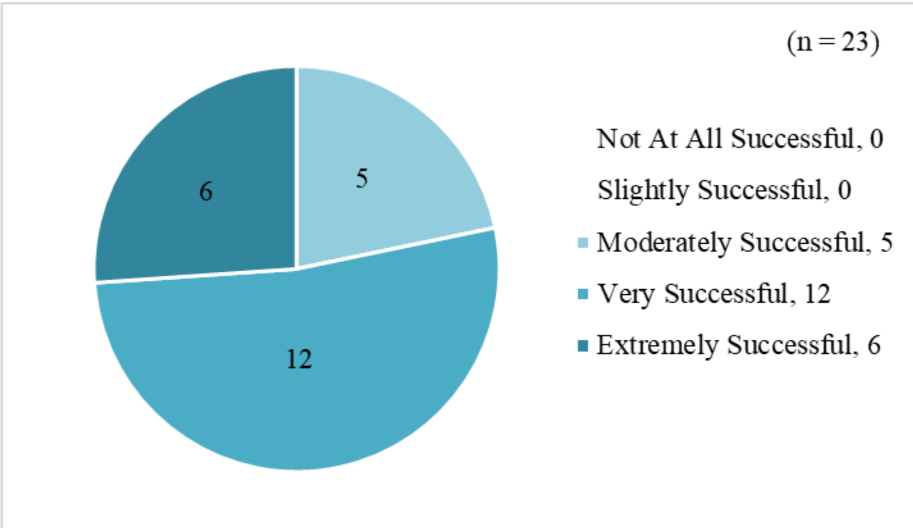
Number of Organizations that Use Specific Indicators of Successful Filter Adoption



Organizations were also asked to rate their program's success on a five-point Likert scale from "Not at all successful" to "Extremely Successful" (Q22). This question has the potential to introduce a significant amount of response bias, but it was positioned after Question 22 in hopes that respondents would consider how their organizations succeeded in reference to the indicators they selected in the previous question. Figure 20 shows that no organizations gave a self-rating of "Not at all Successful" or "Slightly Successful." Five of the 23 organizations rated their programs as "Moderately Successful." Over half of the organizations (12 of 23) gave their programs a rating of "Very Successful," and six selected "Extremely Successful."

Figure 20

Program Success Rating According to Organizations



Individual organization's responses to Questions 21 and 22 are displayed in Table 2. A check mark represents an organization's acknowledgement of an indicator that it looks for to determine whether filters have been "successfully adopted." The 23 organizations have selected, on average, nearly five indicators each. Only two organizations selected one indicator of adoption (Orgs. 1 and 3), and only one organization selected all eight pre-established indicator responses (Org. 9). The far-right column of Table 2 is a representation of the responses to Question 22 in numeric format from 1 to 5, with "Extremely Successful" being equivalent to 5. The total row at the base of the table indicates the total number of organizations that selected a given success indicator or responded to the question.

Table 2

Successful Adoption Indicators Identified by Individual Organizations

Org ID	Demonstrate Correct Filter Use in Intervention	Self-Reported Improved Health	Demonstrate Correct Filter Use in Follow Up	Filter Present in Follow Up	Reported Satisfaction	Increased Filter Demand	Improved Local Health Records	Water Quality Testing in Follow Up	Other (Reduction in Medical Costs)	Program Success Rating (1-5)
1					✓					3
2		✓					✓			4
3	✓									4
4	✓	✓	✓	✓	✓	✓	✓			4
5	✓	✓	✓	✓	✓	✓				5
6	✓	✓	✓	✓	✓					3
7		✓			✓	✓				3
8	✓		✓	✓						4
9	✓	✓	✓	✓	✓	✓	✓	✓		5
10	✓	✓	✓	✓						4
11	✓	✓	✓	✓			✓			4
12	✓	✓	✓	✓	✓	✓	✓			4
13	✓	✓	✓	✓	✓	✓				5
14		✓	✓	✓	✓	✓	✓		✓	4
15	✓	✓	✓	✓	✓	✓				3
16	✓	✓	✓	✓	✓	✓				5
17	✓	✓	✓	✓	✓	✓				3
18	✓				✓	✓				4
19	✓	✓	✓	✓	✓	✓	✓			5
20	✓		✓		✓	✓				5
21	✓	✓	✓	✓						4
22	✓	✓	✓	✓						4
23	✓	✓	✓	✓	✓	✓				4
Total	19	18	18	17	16	14	7	1	1	23

It is important to note that the majority of the indicators of successful adoption responses from Question 22 are dependent on follow up evaluation, except "Demonstrate correct filter use in intervention." Organization 14 selected all responses as indicators of adoption except "Water quality testing" and "Demonstrate correct filter use in intervention" because, according to this organization, if a beneficiary can demonstrate the steps to using the filter directly after they have been shown them, it does not necessarily mean that they will continue to use it correctly. However, the majority of organizations (19 of 23) checked "Demonstrate correct filter use in intervention" as being a success indicator, which means that part of their confirmation of filter adoption is not dependent on post-intervention monitoring and evaluation.

Adoption Domain Results

As detailed in the methodology section "Weighing and Combining of the Domains," each organization has received a score for each adoption domain based on their responses and how the domains are defined. Each organization has a cumulative score for each of the domains which represents a percent of the total points available in the domain. These results answer the second research sub-question, "How sensitive are organizations to barriers and enablers of filter adoption?" by showing each organization's sensitivity to the five different adoption domains. Figure 21 is a collection of graphs that show the score of each organization for each of the five domains as represented by *(a)* User Preferences (UP), *(b)* Integration and Collaboration (I&C), *(c)* Government Influence (GI), *(d)* Resources and Collaboration (R&C), and *(e)* User Training (UT). Graph *(f)* shows all domain scores for each organization side-by-side for better comparison. All scores are rounded to the nearest whole number, and means and standard deviation calculations are rounded to the nearest tenth.

Graph *(a)* of Figure 21 shows the User Preferences (UP) score for each organization. The average score among the 23 organizations is 49.3 with a standard deviation of 20.7. The highest UP score is 84 (Orgs. 9 and 22), the lowest UP score is 16 (Org. 8), and the mode is 31, with five occurrences. Note that Org. 3 has received 0 out of 16 potential points because it left four responses to Question 6 blank (each response yielded a maximum of four points for the UP domain). All other survey questions were complete. In efforts to include this organization in the rest of the analysis, an assumption has been made that Org. 3 will receive no points for neglecting to fill in the aforementioned responses. Though this assumption has the potential to drastically affect Org. 3's total scoring in the UP domain, four other organizations have the same score, and two have even lower scores.

Graph *(b)* of Figure 21 shows the individual scores in the Integration and Collaboration (I&C) domain. The average score is 53.8 with a standard deviation of 24.6. The highest I&C score is 94 (Org. 4), and the lowest is 19 (Orgs. 7, 8, and 11). The most common score is 69 with four occurrences.

Graph *(c)* shows the cumulative Government Influence (GI) scores of individual organizations. The average score of the 23 organizations is 41.9 with a standard deviation of 30.8. This is the highest standard deviation of the five domain score means (by more than 6 points), which means that the data are more spread out relative to the average cumulative GI score. This is evident in that GI is the only domain category where at least one organization has a cumulative score of zero. In fact, six organizations have a score of 0 (Orgs. 1, 2, 3, 7, 17, and 22), and the highest score is 88 (Org. 9). In addition, there are seven occurrences of the score 63. This score is more frequent compared to the other domains' modes because the GI domain had the lowest maximum points as a result of the weighing and combining process.

Graph *(d)* displays the total scores of organizations for the Resources and Communication (R&C) domain. The average RC score is 55.2 with a standard deviation of 21.0, and a mode of 31 (four occurrences). The highest score in the domain is 94 (Org. 14), and the lowest is 19 (Org. 18).

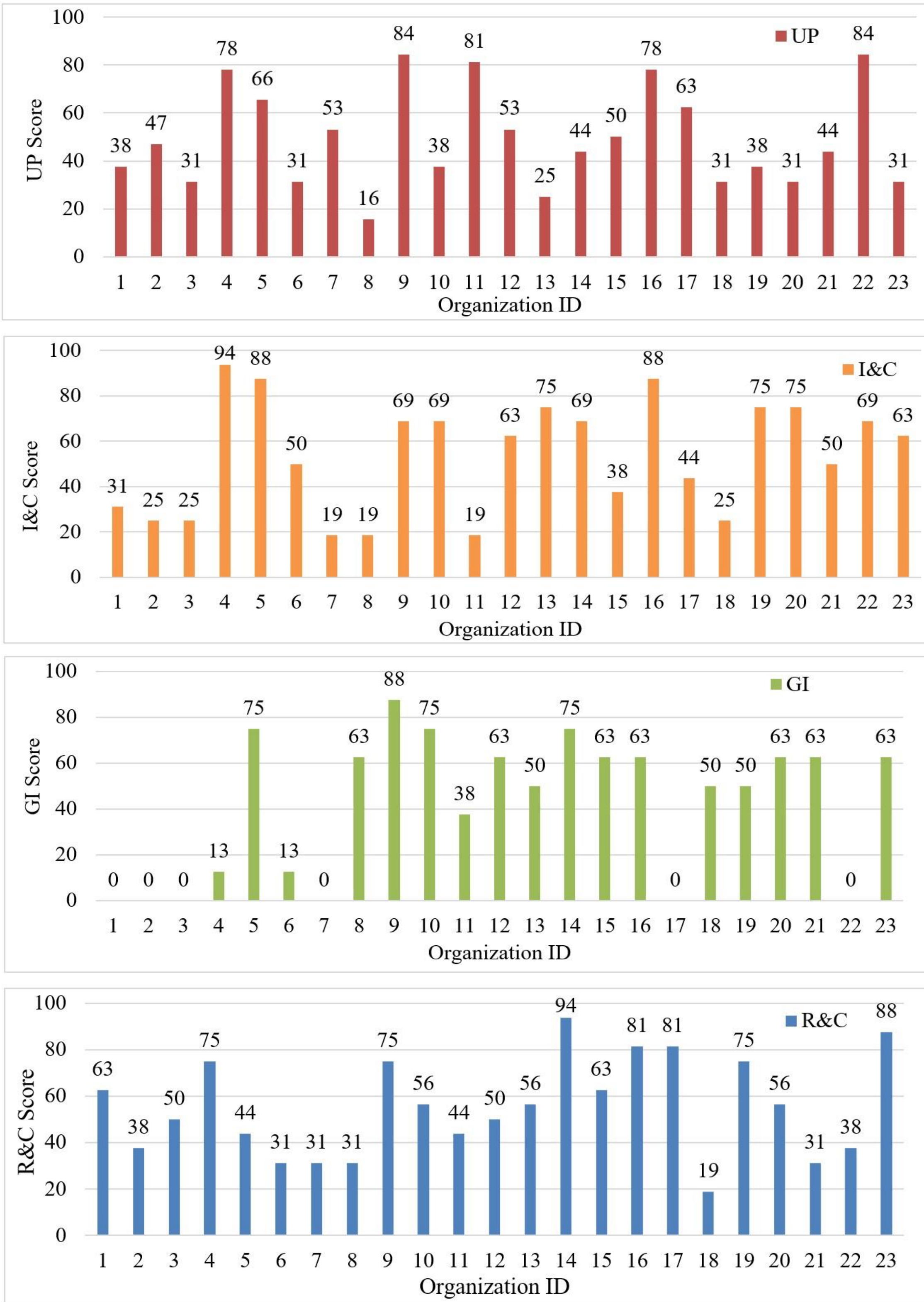
Graph *(e)* shows the User Training (UT) cumulative domain scores by organization. The average UT score is 61.3 and the standard deviation is 21.1. The highest UT score is 91 (Orgs. 9, 14, and 15), and the lowest is 18 (Org. 2). The most frequent score is 55 with five occurrences.

Graph *(f)* of Figure 21 provides a helpful visualization of all the five domain scores for each organization. There appears to be a relationship between scoring no points in GI and scoring low in the other categories, as four organizations that score zero in the GI domain score 63 or less in all other domains (the exceptions being Orgs. 17 and 22, which score over 63 in two domains each). However, some organizations show no relationship between scoring low in GI and the other domains; for example, Org. 4 scores only 13 in GI and scores 55 or more in all the other domains.

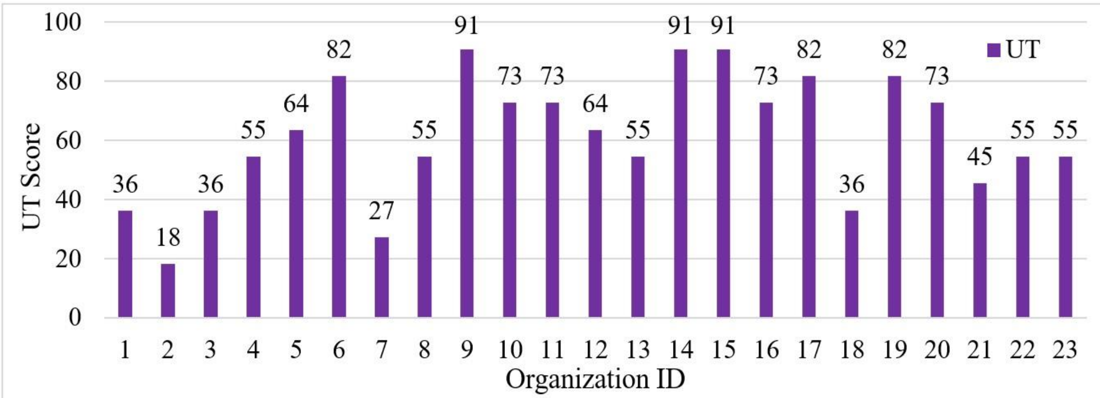
Figure 21

Adoption Domain Results

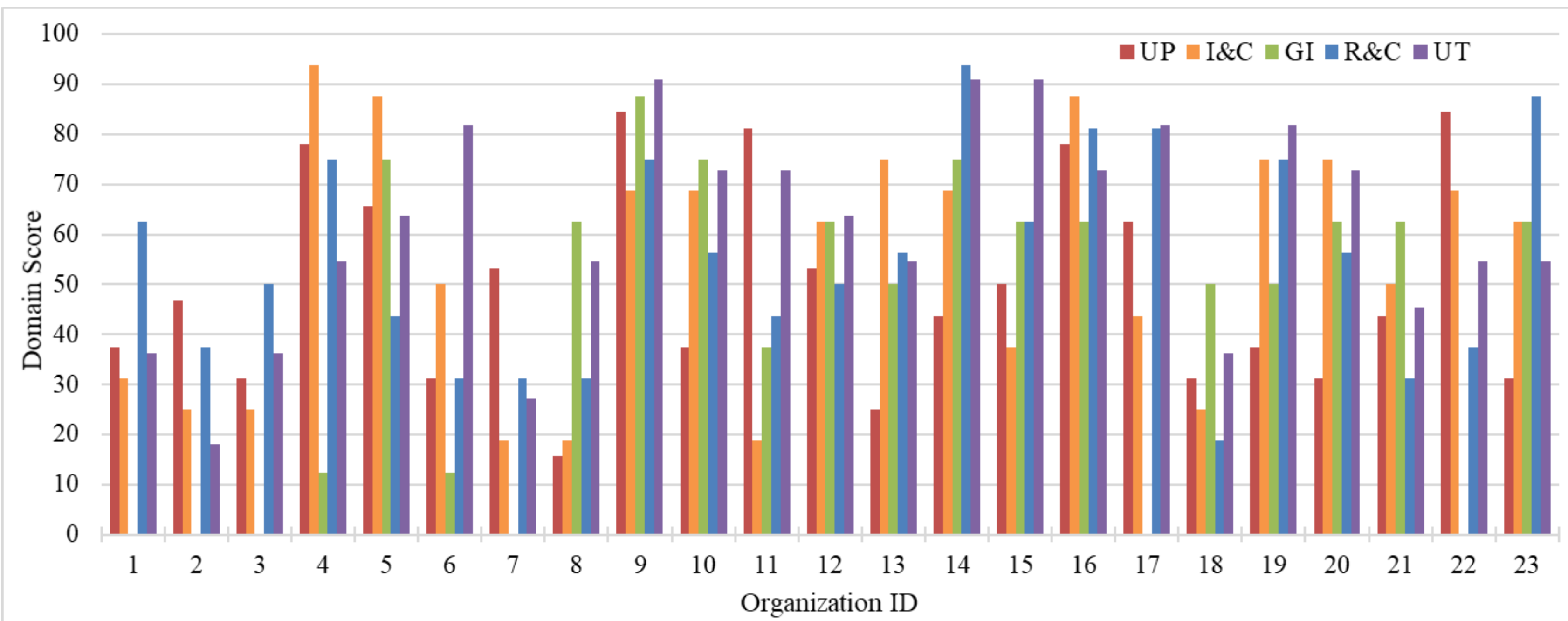
(a) *(b)* *(c)* *(d)*



(e)



(f) All Domain Scores for Each Organization

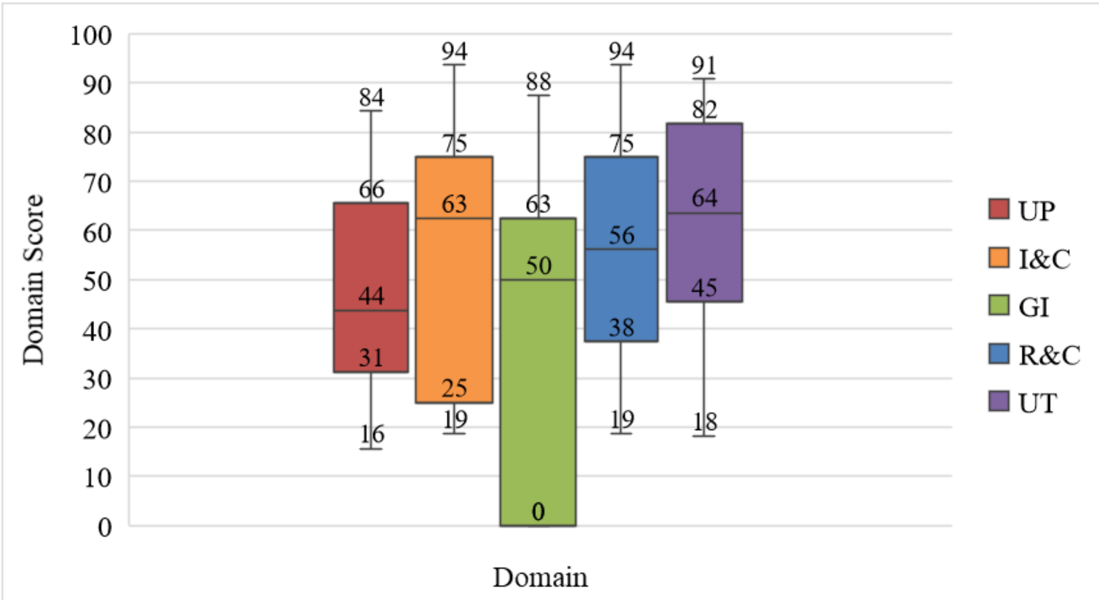


Some organizations score similarly in all five domains. This is analyzed by calculating the average and standard deviation of the five domain scores for each organization (this mean of the five domain scores is hereto called “total mean” for clarity). For example, Org. 12 has the least variation from its mean of 58.4 for all domains with a standard deviation of 6.3. Org. 9 (total mean equals 81.3) and Org. 16 (total mean equals 76.4) also have low spread from the mean with standard deviations of 9.2 and 9.4, respectively. The largest deviation in the total mean is exhibited by Org. 17, which has a total mean of 53.9 and a standard deviation of 33.9. This large deviation from the mean can be attributed to the zero GI score.

Figure 22 shows the range and quartile distribution of the organizations’ scores in each of the five domains. The UP distribution has the lowest range of 68, and the third quartile is at 66, meaning that 75% of the organizations scored equal to or less than 66 points in this domain. The I&C and R&C domains have the exact same range over the same scores, but the median score for I&C is seven points higher. As confirmed in graph *(c)* of Figure 21, the GI distribution of scores is skewed towards zero. This box plot shows that on quarter of organizations’ scores are equal to or between 50 and zero, and at least another quarter of the organizations (6 of 23) scored zero points in the GI domain. This is the only domain where some organizations scored 15 points or less. The UT domain has the highest median at 64 (and the highest mean at 61), and at least 75% of the organizations scored at least 45 points or higher.

Figure 22

Box Plot of Domain Score Distributions



Results of *t*-tests

Independent sample *t*-tests assuming unequal variance were used to evaluate the relationship between the adoption domain means of the group of organizations that selected a successful adoption indicator and the group that did not. Because *t*-tests were run on the first seven success indicators in combination with each of the five adoption domains, 35 tests were conducted (the "Water quality testing in follow up" and "Other" adoption responses could not be used for *t*-test analysis because they have only one response each).

Table 3 shows the results of the *t*-tests. The far-left column shows the success indicator, the second column shows the Test ID number for reference, and the third column shows the adoption domain that is being tested. The next set of columns show the mean of the adoption scores of the group that selected the success indicator ("Yes" group) and the mean of the adoption scores of the group that did not select that indicator ("No" group). Standard deviation is presented in Table 3 for the "Yes" and "No" groups because it describes how much observations in the data set differ from the arithmetic mean. Standard deviation was calculated from the *t*-test output variance, which represents the average of the squared differences from the mean.

The last columns in Table 3 show the *t* statistic and *p*-value calculated from the two tailed *t*-test results. As presented in the methodology, the null hypothesis is that there is no difference between the means of the two groups, and the alternative hypothesis is that there is a difference between the means of the two groups. Two-tailed results are shown because the alternative hypothesis does not specify the direction of the difference between the means. The difference between the means of the "Yes" group and "No" group is statistically significant when the *p*-value is less than the significance level, which was set to .05.

Table 3

t-test Results for Means of "Yes" and "No" Groups for Each Adoption Domain

Success Indicator	Test ID	Adoption Domain	Mean "Yes"	Mean "No"	SD "Yes"	SD "No"	Observations "Yes"	Observations "No"	*t* Stat	*p*-value (two-tail)
Demonstrate Correct Filter Use in Intervention	1	UP	50.2	45.3	22.7	6.5	19	4	0.791	0.439
	2	I&C	57.6	35.9	23.9	22.5	19	4	1.731	0.144
	3	GI	46.7	18.8	27.9	37.5	19	4	1.411	0.231
	4	R&C	54.9	56.3	20.2	28.4	19	4	-0.088	0.934
	5	UT	65.1	43.2	16.7	32.7	19	4	1.305	0.283
Self-Reported Improved Health	6	UP	54.9	29.4	19.8	8.1	18	5	4.308	**< 0.001**
	7	I&C	59.0	35.0	23.0	22.8	18	5	2.081	0.083
	8	GI	43.8	35.0	31.0	32.4	18	5	0.540	0.609
	9	R&C	58.3	43.8	21.1	18.2	18	5	1.527	0.171
	10	UT	65.2	47.3	21.0	16.3	18	5	2.033	0.076
Demonstrate Correct Filter Use in Follow-Up	11	UP	51.9	40.0	22.4	9.7	18	5	1.741	0.101
	12	I&C	61.8	25.0	21.6	4.4	18	5	6.729	**< 0.001**
	13	GI	50.7	10.0	26.9	22.4	18	5	3.435	**0.009**
	14	R&C	59.4	40.0	20.5	16.9	18	5	2.162	0.063
	15	UT	69.7	30.9	14.6	8.1	18	5	7.741	**< 0.001**
Filter Present in Follow Up	16	UP	53.1	38.5	22.5	9.4	17	6	2.188	**0.041**
	17	I&C	61.0	33.3	22.0	20.8	17	6	2.761	**0.022**
	18	GI	50.0	18.8	27.6	29.3	17	6	2.279	0.052
	19	R&C	59.6	42.7	21.1	16.5	17	6	1.992	0.072
	20	UT	69.5	37.9	15.1	18.6	17	6	3.762	**0.007**
Reported Satisfaction	21	UP	49.6	48.7	19.3	25.4	16	7	0.088	0.932
	22	I&C	60.2	39.3	23.3	22.7	16	7	2.011	0.067
	23	GI	45.3	33.9	29.9	33.6	16	7	0.772	0.458
	24	R&C	61.3	41.1	21.9	9.4	16	7	3.097	**0.005**
	25	UT	65.9	50.6	20.6	19.5	16	7	1.695	0.116
Increased Filter Demand	26	UP	51.8	45.5	19.6	23.0	14	9	0.679	0.508
	27	I&C	62.9	39.6	23.3	20.3	14	9	2.543	**0.020**
	28	GI	50.9	27.8	27.5	31.7	14	9	1.795	0.093
	29	R&C	63.4	42.4	21.9	11.6	14	9	2.998	**0.007**
	30	UT	66.9	52.5	20.0	20.7	14	9	1.643	0.119
Improved Local Health Records	31	UP	60.7	44.3	19.8	19.6	7	16	1.828	0.095
	32	I&C	58.9	51.6	27.2	24.0	7	16	0.619	0.550
	33	GI	46.4	39.8	32.0	31.0	7	16	0.458	0.656
	34	R&C	64.3	51.2	20.6	20.6	7	16	1.404	0.188
	35	UT	67.5	58.5	25.6	19.1	7	16	0.834	0.426

Note. *p*-value results that are statistically significant ($p < .05$) are **bolded**.

Demonstrate Correct Filter Use in Intervention (Tests 1-5)

Tests 1 through 5 show the *t*-test results for the domains under the first success indicator, "Demonstrate correct filter use in intervention". No statistically significant group differences are observed for all five of the UP, I&C, GI, R&C, and UT adoption domains (*p's* > .05).

Self-Reported Improved Health (Tests 6-10)

Tests 6 through 10 were conducted on the group of organizations that selected the "Self-reported improved health" indicator versus the group that did not select it. Test 6 shows statistically significant group differences ($t = 4.308$; $p < .001$), where the "Yes" group scored higher (M = 54.9; SD = 19.8) in the UP domain than the "No" group (M = 29.4; SD = 8.1). Tests 7-10 show no statistically significant group differences for the other four domains; I&C, GI, R&C, or UT (*p's* > .05).

Demonstrate Correct Filter Use in Follow up (Tests 11-15)

Three of the five tests conducted for the success indicator "Demonstrate correct filter use in follow up" result in significant differences between the "Yes" and "No" group means. In Test 12, the I&C domain group results are statistically significant ($t = 6.729$; $p < .001$), such that the "Yes" group that selected this success indicator scored higher (M = 61.8; SD = 25.0) than the "No" group that did not select it (M = 21.6; SD = 4.4) in the I&C domain. Test 13 on the GI scores is also statistically significant ($t = 3.435$; $p = .009$), and the mean difference between the "Yes" group (M = 50.7; SD = 26.9) is higher than the "No" group (M = 10.0; SD = 22.4). Test 15 for the UT domain is statistically significant ($t = 7.741$; $p < .001$), so the UT mean score is higher for the group of organizations that look for demonstrating correct filter use in follow up as a success indicator (M = 69.7; SD = 14.6) than the mean of those that do not (M = 30.9; SD = 8.1). The UP and R&C group differences, as shown in Tests 11 and 14, are statistically insignificant (*p's* > .05).

Filter Present in Follow up (Tests 16-20)

Tests 16 through 20 reflect the *t*-tests conducted on the domain scores of the group of organizations that selected “Filter present in follow up” as a success indicator and the group of organizations that did not. For Test 16, the UP score differences are statistically significant (*t* = 2.118; *p* = .041), with the “Yes” group scores (M = 53.1; SD = 22.5) higher than the “No” group scores (M = 38.5; SD = 9.4). Test 17 shows that the “Yes” group scores (M = 61.0; SD = 23.3) are also significantly different from the “No” group scores (M = 33.3; SD = 20.8) in the I&C domain (*t* = 2.761; *p* = .022). No statistically significant group differences are observed in either the GI domain (Test 18) or R&C domain (Test 19) results. Test 20 shows there is a statistically significant difference (*t* = 3.762; *p* = .007) between the UT scores of the group of organizations that use this success indicator (M = 69.5; SD = 15.1) and the group of organizations that do not (M = 37.9; SD = 18.6).

Reported Satisfaction (Tests 21-25)

Tests 21 through 25 are the *t*-test results of the domain scores of the group of organizations that use reported satisfaction as a successful adoption indicator versus the domain scores of the organizations that do not use this indicator. In Test 24, statistically significant differences emerge in the R&C adoption domain (*t* = 3.097; *p* = .005) between the “Yes” group scores (M = 61.3; SD = 21.9) and the “No” group scores (M = 41.1; SD = 9.4). No statistically significant group differences are observed for the other tests in the UP, I&C, GI, and UT domains (*p's* > .05).

Increased Filter Demand (Tests 26-30)

Tests 26 through 30 compare the domain means between the group of organizations that selected “Increased filter demand” as an indicator of successful adoption and the organizations that did not. Two tests result in statistically significant group differences: Test 27 on the I&C scores (t = 2.543; p = .020) and Test 29 on the R&C scores (t = 2.998; p = .007). The “Yes” group scores for I&C (M = 62.9; SD = 23.3) and R&C (M = 63.4; SD = 21.9) are higher in than the respective “No” group scores (I&C: M = 39.6; SD = 20.3; R&C: M = 42.4; SD = 11.6).

Improved Local Health Records (Tests 31-35)

Tests 31 through 35 are conducted on the domain scores of the group of organizations that said improved local health records are an indicator of successful adoption compared to the scores of the group that did not. No statistically significant group differences are observed for all five tests (*p’s* > .05), meaning that the null hypothesis cannot be rejected for this success indicator.

Chapter 5: Discussion and Conclusions

This chapter provides discussion of the study results and conclusions drawn that have implications for the field of water, sanitation, and hygiene research.

Discussion of Domains

One should note that the way that the domains have been defined is very specific to questions and responses that constitute the survey instrument developed in this study. An organization's score is in no way an assessment of whether an organization does better work, is more impactful, or is more successful than another. Rather, the purpose of the domain scoring is to evaluate how sensitive an organization is to the adoption domains according to their specific definitions, and whether this sensitivity relates to what constitutes an indicator of successful filter adoption. The following subsections expand upon and discuss the results of the domain scoring process.

User Preferences

User preferences impact the adoption of water treatment products. This domain has been defined by awareness of the impact that beneficiaries' social economic status, gender, perception of the need to treat their water, familiarity of the technology, and norms within the culture may have on adoption. Based on the research studies by Daniel et al., a household's perception of the need to drink water is a precursor for successful adoption (Daniel et al., 2018), and exposure to household water treatment (HWT) promotion is one of the most influential socio-economic characteristics on HWT adoption (Daniel et al., 2019). In this study, 21 of the 23 surveyed organizations always or often consider a beneficiary's perception of the need to treat water, but only 8 of 22 organizations always or often consider the beneficiary's familiarity or exposure to the filter technology. The survey also shows that more organizations seldom or never consider the spiritual or religious beliefs, gender, or exposure to the technology than those that do, and a little over half are always or often aware of cultural norms (13 of 22) or the beneficiary's socio-economic status (14 of 23) which may impact filter adoption. Whether or not these beneficiary traits do have an effect on filter adoption, it is imperative that implementing organizations are aware of them and how they may influence the beneficiary's behavior and preferences.

Other components that are considered in this domain are whether an organization is considering what users like about the filters, whether beneficiaries have agency in choosing the filter over other HWT technologies, and how user preferences are leveraged to communicate the effectiveness of the filters at improving water quality. The survey revealed that three of the 23 organizations "sometimes" give beneficiaries the option of choosing a water treatment product other than the hollow fiber membrane filter, but 20 do not. Product choice increases the likelihood of HWT adoption, and including the beneficiary in the HWT decision making promotes self-efficacy and ownership (Ojomo et al., 2015). Though offering a range of HWT technologies may not be feasible for nonprofit organizations, having options may be effective for sustained use.

Overall, the organizations that scored in the upper quartile of this domain have scores that range from 66 to 84 on a scale of 0 to 100. Five organizations scored over 75 (Orgs. 4, 9, 11, 16, and 22), which means that they are sensitive to the components used to define this User Preferences domain. However, other organizations that scored lower in this domain may be sensitive to user preferences in a way that was not captured by this domain because of the limitations of its definition.

Integration and Collaboration

Although a small, specific subset of people are typically the recipients of household water treatment products, collaboration involving a variety of actors is essential for influencing sustained use (Ojomo et al., 2015; USAID, 2007). Humans are largely influenced by their peers and their social networks, so these relationships can be leveraged to influence HWT uptake and continued use. Which entities are involved and at what point in the program they are included is highly dependent on the context of the program.

This study found that community leaders are the group most commonly involved during the HFM filter intervention phase. These community leaders are often involved in training filter beneficiaries on how to use and maintain the filter. However, more collaborative partners are involved in the program planning phase than the filter intervention or monitoring and evaluation phases. The local partners are integral in determining who is in most need of the filter. This support helps remove the decision of beneficiary eligibility from the shoulders of organizations that may not have the local knowledge as to which are the households most in need; however, it can also lead to abuse of power. For example, the spokesperson for Org. 12 explained that they quickly learned that using certain community partners in the assistance of beneficiary selection and filter distributions led to harmful power dynamics, in that the partner would restrict beneficiary involvement unless certain requirements were filled. As a result, the organization changed its beneficiary selection to be random from a pool of women with young children who were willing to make a public commitment to sharing their filtered water with neighbors, rather than letting the partners influence who would receive the filters. Therefore, partner involvement comes with its own challenges that can only be navigated using context-specific experience.

Overall, organizations that scored high in this domain demonstrated that they collaborate with multiple community partners throughout the programming process and invest in comprehensive environmental health education during their filter training. Six organizations that scored in the upper quartile of this domain scored between 75 and 94 points out of 100 (Orgs. 4, 5, 13, 16, 19, and 20).

Government Influence

The Government Influence domain evaluates in what capacity distributing organizations involve local governments during programming and how filter certification is leveraged to promote trust in the technology as a water treatment product. On average, the Government Influence domains is where organizations scored the lowest; nearly 35% of the organizations (8 out of 23) scored lower in this domain than they did in any of the other four. The upper quartile of scores range from 63 to 88 points, and four organizations scored 75 points or higher (Orgs. 5, 9, 10, and 14).

A few organizations mentioned in the phone conversations that they distribute the filter that they do because it provides absolute-size pores or it meets certain certification of microbial reduction (Orgs. 8, 12, and 20). Though product certification may be important to distributors, it does not necessarily coincide with involving local government throughout the programming phases. This may be because local governments are less supportive and cooperative in certain regions than others. For example, Org. 18 reported that it tried to avoid working with the local government because of its lack of support. Regardless, this Government Influence domain is the one to which, on average, the organizations surveyed in this study are less sensitive. This may be partly because the domain is defined by less survey responses than the others, and therefore, has the least amount of points obtainable.

Resources and Communication

The Resources and Communication domain is defined to evaluate how beneficiaries finance the filters, if they have opportunities to communicate filter issues, and the likelihood of accessing filter system parts locally. The upper quartile of organization scores ranged from 75 to 94 points. Seven organizations scored 75 points or higher (Orgs. 4, 9, 14, 16, 17, 19 and 23), which is the highest number of organizations to score 75 points or higher out of all the domains.

One of the components measured in this domain is accessibility to communication channels where beneficiaries can report issues with the filtration systems. Field studies show that household water treatment technologies are not as effective as their lab results claim to be because of their lack of extensive and long-term testing in real-world applications. There is great disconnect between those who design and manufacture the products and those who use them. Murray et al. state that, "[d]espite the importance of understanding consistent use, barriers to use, and microbiological effectiveness to optimize HWT success in households, these metrics are not systematically measured, reported, or addressed within the product design cycle" (2019, p. 2). Therefore, it is evident there is a lack of robust feedback and communication between those who design the water treatment technologies and those whose livelihood depends on them.

This feedback loop can be strengthened by the distributing organizations that can act as a liaison between filter recipients and manufacturers. Organizations have the opportunity to collect user feedback on what they like about the HWTS product, what makes it difficult to use, and what issues are most affecting uptake and proper use. This feedback should be reported directly to the suppliers and/or manufacturers so that users' preferences can impact the design. All but two of the 23 organizations surveyed for this study provide a channel for beneficiaries to report filter issues. Therefore, they have the opportunity to report common issues which can be addressed by manufacturers. Though the communication link between organizations that distribute the filters and the companies that sell the filters was not specifically evaluated in this research, it is an opportunity for future work and discovery.

Another important component of this domain is the investment required of beneficiaries. The CAWST recommends that beneficiaries be responsible for an in-kind or small financial contribution to ensure ownership and sustained use (Schuelert et al., 2011). In addition, research shows that giving out HWTs for free can undermine appropriate adoption and use (Blanton et al., 2014; Clasen, 2009; Ojomo et al., 2015; Rayner et al., 2016). Only five of the 23 organizations surveyed required some buy in or financial investment from beneficiaries for the HFM filters. However, ownership of the filter can be encouraged in other ways. For example, even though it provides the filters for free, Org. 12 requires that beneficiaries make a commitment to share their filter with their neighbors, which can be manifested as a personal investment that is driven by a responsibility to others. Regardless of how ownership is fostered, it is imperative that beneficiaries' agency is supported through their investment in the water filtration process. This component of the Resources and Communication domain can be expanded to investigate other ways that organizations are fostering ownership of HWT technologies like filters.

The Resources and Communication domain also includes the ability to source filter parts locally. If filter parts cannot be easily sourced locally, as over half of the organizations reported, then the sustainability of these HFM interventions is dependent on the availability and access to replacement parts and distribution locations (Ojomo et al., 2015). A few organizations mentioned this limitation of the HFM and that they are not meant to be long-term water treatment solutions (Orgs. 4, 8, and 13). However, the bucket is the component of the filtration system that is commonly accessed locally, with 19 of 23 organizations saying it is always sourced locally. In defining this domain, higher likelihood of using a locally sourced bucket equates with more points. In addition, organizations that distribute bucket adapter systems often ask the beneficiary to source the bucket themselves as a buy in, but this may not always be appropriate. For example, the representative of Org. 12 explained that beneficiaries are not asked to bring their own bucket to the filter training as a buy-in because the buckets they bring are often of poor quality. They may have been sourced from a dump and once contained chemicals, or they are too structurally weak to withstand the installation of the filter and daily use. This is certainly an example of how using a bucket as a buy-in incentive would be inappropriate and potentially harmful to filter beneficiaries. This also may be a reason why buckets are not sourced locally and rather are bought and brought in to ensure their integrity. This is knowledge that can only be gained from on-the-ground work and observation and which was revealed through the qualitative element of this study.

User Training

The User Training domain is where organizations, on average, have the highest score. This means this is the adoption domain to which organizations are most sensitive. This is understandable, because the components that make up the User Training domain directly relate to the "software," or training resources, monitoring, and evaluation that is required with implementing a technology. The upper quartile of scores for this domain range from 82 to 91 points. Six organizations scored 75 points or higher out of 100 (Orgs. 6, 9, 14, 15, 17, and 19).

Monitoring and evaluation practices like follow ups are integral to understanding successful filter adoption. With the introduction of a new technology comes the accompanying behavior change and practices of using and maintaining the technology. Evidence of behavior change can only be assessed over time with follow up evaluation (Hulland et al., 2015). In fact, the majority of the indicators of successful adoption responses from Question 22 of the survey are dependent on follow up evaluation, excepting "Demonstrate correct filter use in intervention." Therefore, implementing organizations that invest in multiple follow ups visits have the capacity to anticipate and respond to issues that affect behavior change and filter use.

User training can be largely influenced by recommendations of the supplier. For example, Sawyer recommends that the first follow up should be conducted at two weeks, and a second follow up to evaluate behavior changes should be conducted at eight weeks (Sawyer, 2021). Village Water Filters recommends that, during the training, the beneficiary should demonstrate how to assemble, disassemble, and backflush the filter three times with real water and without assistance to ensure that understanding is cemented through experience (Village Water Filters Inc., 2018a). The influence of the suppliers/manufacturers on filter implementation methods was not explicitly evaluated in this study, but it did have some impact on the survey development. For example, I originally designed the survey so that representatives could indicate only two follow ups and their time since distribution. However, after communicating with an organization that said Sawyer recommended them to conduct three follow ups, I modified the survey so that respondents could indicate three follow ups if applicable (Organizations that had filled out the survey prior were contacted and their responses were updated).

The Importance of All Domains

Categorization of factors that influence HWTS adoption, like the adoption domains used in this study, is a way to group factors that are related. However, all adoption domains are significant, and even more importantly, they are interconnected. For example, some collaborative groups meant to encourage adoption are not beneficial if they are not included in the monitoring and evaluation process. In their systematic review of literature, Hulland et al. (2015) found that advisory committees do not always successfully influence change, especially if there is no follow up support. In this study, of the nine surveyed organizations that reported establishing a water council or support group to encourage filter use (Integration and Collaboration domain), only four conduct follow up at or after six months, and one does not conduct any follow ups at all (User Training domain). This means that the support groups that are established during the intervention may not be sustained if they do not receive appropriate follow up.

Relationship Between Domains and Defining Successful Adoption

As indicated by the *t*-test results of this study, the organizations that are more sensitive to user preferences are likely to view self-reported evidence of improved health and the filter's presence during follow up as indicators of successful adoption. This is because organizations that are sensitive to user preference are likely to give weight to the beneficiary's experience with and preference for the filter and how it has impacted their health and wellbeing.

Organizations in this study that focus on integrating local partners as well as additional environmental health education into their programming and training are likely to view the filter's presence at follow ups, demonstrations of correct filter use during follow ups, and an increase in filter demand as indicators of successful filter adoption. This is because partnerships can help foster accountability, and partnering entities may even be involved in and driving the follow up process to evaluate filter uptake and demand.

Organizations that involve government partnerships in their programs and use certification to help persuade filter adoption are likely to view demonstration of correct filter use during a follow up as an indicator of successful adoption. Sensitivity to government influence relates to utilizing this success indicator because partnering with local government may require follow up evaluation and valuing product certification may coincide with assurance that it is being used appropriately.

Organizations that are sensitive to the accessibility of resources and that provide communication channels are more likely to use indicators like reported satisfaction and increased filter demand to define successful filter adoption. These indicators of successful adoption correspond with providing beneficiaries with the opportunities to communicate their preferences. In addition, it may be that when replacement filter parts are locally available, distributing organizations are more likely to define success by tracking and meeting demand over time.

And finally, organizations that have a strong user training focus are likely to define successful filter adoption through follow up evaluation, including evidence that the filter is present and that beneficiaries can demonstrate correct filter use. This supports the expectation that organizations that use follow up visits to determine filter adoption must have a robust monitoring and evaluation process.

Limitations of the Study

This study was conducted by surveying members of a subset of nonprofits and nongovernmental organizations that currently have a HFM filter distributing program. It assumes that participants truthfully and accurately relayed their organizations' methods and actions, because survey responses could not be independently verified. Organizations were asked to complete the survey for one of their programs, even if they had multiple programs that involved household HFM distributions. Therefore, the organizations' responses to the survey are not necessarily indicative of their entire scope and programming. In addition, the 23 distributing organizations interviewed in this study are not necessarily representative of all organizations that distribute HFM filters or all entities that focus their efforts on household water treatment and safe storage implementation. In addition, this study focused specifically on distributors of Sawyer, Village Water Filters, and Uzima HFM filters, so although some intervention methods and the resulting factors of adoption can translate to other household water treatment technologies, some are specific to these particular water treatment products.

The *t*-tests used for statistical analysis assume that the independent samples from the populations were normally distributed. The tests were conducted assuming unequal variance and the significance level was set to .05. These tests were limited by the amount of data available and the unequal number of observations between the two groups. Organizations that were surveyed in this study elected to respond and participate, which may create bias, and their responses cannot be assumed to represent all organizations that distribute HFM filters.

Opportunities for Future Research

Opportunities for future research include using this or a similar adoption domain framework to evaluate implementers' sensitivity to factors that affect the adoption of water treatment products and other WASH related behavior change. With enough widespread use and testing across different HWT implementers, this adoption framework could potentially be developed into an interactive tool that would take implementers' inputs of what products they distribute and what methods they use to conduct their programming, calculate the implementers' sensitivity to different factors of adoption, and present suggestions for ways implementers can strengthen their sensitivity to factors that affect adoption and sustained use of the HWT technologies they distribute.

In this study, the purpose of the survey was to collect the responses that were used in the adoption domain scoring process. However, there is an opportunity to explore whether there are relationships between the context of the surveyed programs—like program type, region of distributions, number of filters distributed, and number of individuals impacted—and how organizations answered specific survey questions. Future research can also build on this study to identify the relationship between sensitivity to adoption domains and definitions of successful adoption of distributors of products other than hollow fiber membrane filters. Because each HWT technology requires different implementation methods, training, and maintenance, it would be interesting to evaluate if differences arise among the major classes of water treatment products.

Another opportunity for future research is to investigate channels of communication throughout the life-cycle of the HWT product, through design, manufacture, distribution, implementation, and follow up. Because user preferences are so impactful on HWT uptake, it is critical to evaluate how these preferences are or are not being considered by manufacturers and the role of implementers in passing on this information. In addition, HWT suppliers often develop best practices on how partnering organizations should implement their products in communities. Organizations like Sawyer, Uzima, and Village Water Filter have recommendations on how to teach beneficiaries appropriate use and maintenance of the product, as well on how to educate beneficiaries on the importance of basic hygiene and sanitation (Sawyer, 2021; Uzima Water Filters, 2021b; Village Water Filters Inc., 2018a). The influence of product suppliers on how implementers conduct their programming is not well quantified, but it is imperative to study in order to better understand how relationships all along the HWT product life-cycle impact adoption and sustained use of that product.

Conclusions

This research has demonstrated how an adoption domains framework can be applied to survey responses in order to evaluate an implementing organization's sensitivity to factors that influence HFM filter adoption. This process can be translated to assessing how other implementers of household water treatment technologies influence adoption of the products they distribute. The five adoption domains of User Preferences, Integration and Collaboration, Government Influence, Resources and Communication, and User Training have been defined and applied specifically to distributors of HFM filters, but these domains can be expanded and modified in order to be applicable to other HWT implementing programs. HWT implementers have a unique advantage of accumulating local knowledge, building relationships, and learning from experience lessons that cannot be taught in an academic environment or evaluated in a laboratory. WASH academics and implementers alike are striving for the same goal: to make clean water, sanitation, and hygiene more accessible to those who need it most. This research shows that a framework of classifying factors that affect water treatment product adoption can be applied to the real-world implementation of that product. It emphasizes the necessity of integrating academic research with knowledge gained on the field. In addition, this study highlights that it is critical for organizations that distribute HWT products to be conscious of and responsive to factors that may impede adoption. Appropriate implementation depends on the beneficiary being at the heart of the product choice, program planning, product training, and monitoring and evaluation of the program, and this can be evaluated by applying an adoption domain framework.

In reference to the research question, this study shows that there are relationships between how the surveyed organizations define indicators of successful adoption and how sensitive they are to adoption domains. These relationships are specific to the sample of organizations' programs analyzed in this study, and more research is needed to see whether these trends are evident and translatable to other hollow fiber membrane filter distributors and implementers of different HWT products. However, this research has shown that these relationships are significant because certain indicators of successful adoption are dependent on an organization's responsiveness to particular factors of adoption. For example, if a new HFM implementer wants to use demonstration of correct filter use during follow up as a success indicator but it does not invest in the components like robust filter training and monitoring and evaluation (User Training domain), it will likely not measure successful filter adoption. Therefore, how an organization implements HWT products and its associated awareness of factors of adoption need to be quantified and assessed in order to better understand how implementers define successful adoption.

This study is significant because it highlights the necessity to study whether or not implementers of HWT products are attentive to factors that affect adoption. It fills a gap in the WASH literature by measuring organizations' sensitivity to these adoption factors using an adoption domain framework based on a survey instrument. It reinforces that, in order for technologies like HFM filters to be implemented appropriately, users need to be at the center of the program planning and implementation processes, and indicators of successful and sustained adoption need to be monitored over time. Furthermore, this study contributes to the body of knowledge that aims to make clean water more accessible to those who need it most.

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Appendix A: Survey

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1) For this specific program, in what context does your organization distribute HFM filters to households?

○ Emergency relief

○ Established program with permanent local staff

○ Temporary program with local partners

○ Other ____

2) What type(s) of HFM filter(s) does your organization distribute in this program?

☐ Sawyer Bucket Adapter System with PointONE™ filter

☐ Sawyer Bucket Adapter System with Point ZeroTWO filter

☐ Sawyer Collapsible Bladder Kit

☐ Sawyer MINI (attaches to drinking pouch, straw, or disposable bottle)

☐ Other HFM filters (please specify brands and model numbers)

____

3) Approximately how many filters has your organization distributed over the life of this program?

____

4) Approximately how many people has this filter program impacted since its inception?

____

5) Are the households served by this filter program typically in rural or urban areas?

○ Predominantly urban

○ More urban

○ Equally urban and rural

○ More rural

○ Predominantly rural

6) Before your organization introduces HFM filters to households, how often do you consider the following traits of the beneficiaries? *(beneficiaries are defined as people who have been given the filters and use it within the context of their own home)*

	Always	Often	Sometimes	Seldom	Never
Spiritual or religious beliefs	○	○	○	○	○
Cultural norms	○	○	○	○	○
Gender	○	○	○	○	○
Socio-economic status	○	○	○	○	○
Perception of the need to treat water in the first place	○	○	○	○	○
Knowledge of or prior exposure to filter technology	○	○	○	○	○

7) Please explain how your organization determines who is eligible to receive a filter:

____

____

8) What is the most common financial impact on beneficiaries who receive filters? (check all that apply)

- ☐ The filters are provided free of charge
- ☐ There is a buy-in requirement from the beneficiaries
- ☐ The beneficiaries are charged for the filters at a subsidized price
- ☐ Filters are traded for goods or services
- ☐ Other ____

9) For this program, do beneficiaries have an option to choose a water treatment product other than a HFM filter?

- ○ Yes
- ○ No
- ○ Sometimes

10) What do beneficiaries most commonly report liking about HFM filters? (check all that apply)

- ☐ Social status achieved from filter ownership
- ☐ Aesthetics of the filter system (color, design, size, etc.)
- ☐ Convenience of operation (ease of use)
- ☐ Ability to reduce disease and illness
- ☐ Durability of the filter
- ☐ Our organization does not collect this information
- ☐ Other ____

11) Is there a way that beneficiaries can communicate filter breakage or problems to your organization? (check all that apply)

- ☐ Yes, in person with local staff
- ☐ Yes, via electronic communication (cell phone application, text messaging, or email)
- ☐ Yes, via my organization's website
- ☐ Beneficiaries can report issues to local partnering people/organizations
- ☐ No
- ☐ Other ____

12) How often do beneficiaries reach out for assistance?

- ○ Often
- ○ Sometimes
- ○ Seldom
- ○ Never
- ○ Don't know

13) Please indicate if your organization collaborates with any of the following people or organizations during the three phases of Program Planning, Filter Intervention, and Monitoring and Evaluation: (check all that apply)

	Program Planning:	Filter Intervention:	Monitoring and Evaluation:
	(program research and formation)	(filter distribution and training)	(surveys and follow-ups to evaluate filter adoption)
Community leaders	☐	☐	☐
Teachers or healthcare workers	☐	☐	☐
Local charity organizations	☐	☐	☐
Local government	☐	☐	☐
Other	☐	☐	☐

14) Does your organization assess whether the HFM filters meets local government standards and regulations as a water treatment product?

- ○ Always
- ○ Often
- ○ Sometimes
- ○ Seldom
- ○ Never

15) How likely are beneficiaries to find replacements for broken filter system parts *locally*?

- ○ Extremely likely
- ○ Somewhat likely
- ○ Neither likely nor unlikely
- ○ Somewhat unlikely
- ○ Extremely unlikely

15.1) If applicable, how often are the buckets for the bucket adapter systems sourced locally?

- ○ Always
- ○ Often
- ○ Sometimes
- ○ Seldom
- ○ Never

16) Apart from the filter, what supplemental materials or services does your organization provide for beneficiaries? (check all that apply)

- ☐ Pamphlet or other reading materials about filter
- ☐ Video instructions or demonstration on filter use
- ☐ Phone application
- ☐ Water-council or support group to encourage filter use
- ☐ Other ____

17) Which of the following does your organization use to show beneficiaries that the HFM filters are effective at improving water quality? (check all that apply)

- ☐ Anecdote of improved health associated with using filter
- ☐ Demonstration that the filter reduces turbidity, or cloudiness of the water
- ☐ Statistics of improved health from using filter
- ☐ Reported satisfaction with filter
- ☐ Certification of filter as an effective water treatment product
- ☐ Approval by local leaders or peers
- ☐ Other ____

18) If your organization conducts filter training, please indicate if any of the following topics are covered: (check all that apply)

- ☐ Handwashing at critical times
- ☐ Safe storage practices (like covering open water sources)
- ☐ How to clean and maintain filter parts
- ☐ How to source new parts if any are damaged or lost
- ☐ Hygienic handling of foods
- ☐ Sanitation and treatment of waste
- ☐ Food and nutrition
- ☐ Reducing household air pollution
- ☐ Other ____

19) If applicable, under what context do you train beneficiaries how to use their filter? (check all that apply)

- ☐ Group training led by my organization's staff/volunteers
- ☐ Group training led by community leader
- ☐ Private training in beneficiary's home
- ☐ Mass media advertisement or public events
- ☐ Other ____

20) Which of the following Monitoring and Evaluation does your organization do? (check all that apply)

- ☐ Baseline survey assessment
- ☐ Follow-up survey or visit
- ☐ Second follow-up survey or visit
- ☐ Third follow-up survey or visit
- ☐ We do not conduct Monitoring and Evaluation

20.1) When do you follow up (in reference to time since filter distribution)?

	1-2 weeks	1 month	1.5 months	2 months	3 months	4-5 months	6 months	7-9 months	9-12 months	12+ months
First follow-up	○	○	○	○	○	○	○	○	○	○
Second follow-up	○	○	○	○	○	○	○	○	○	○
Third follow-up	○	○	○	○	○	○	○	○	○	○

21) What indicators does your organization look for to determine whether filters have been "successfully adopted"? (check all that apply)

- ☐ Demonstration of correct filter use by beneficiary during the intervention
- ☐ Local health records indicating improved health
- ☐ Self-reported evidence of improved health (via survey, interview, etc.)
- ☐ Demonstration of correct filter use by beneficiary in follow-up visit
- ☐ Confirmation that filter is present in beneficiary's home in follow up visit
- ☐ Water quality testing in follow up visit
- ☐ Reported satisfaction with filter product
- ☐ Increase in demand for filters
- ☐ Other ____

22) According to your organization, how successful was filter adoption in this program?

- ○ Extremely successful
- ○ Very successful
- ○ Moderately successful
- ○ Slightly successful
- ○ Not at all successful

Vita

Tyree Jae Wilmoth was born in Asheville, North Carolina, to Dirk and Kathryn Wilmoth. She graduated as valedictorian from Patrick Henry High School in Glade Spring, Virginia in June 2014. The following autumn, she enrolled at Centre College in Kentucky. In May 2018, she was awarded a Bachelors of Science in Environmental Physics with honors and became a member of Phi Beta Kappa. In the fall of 2019, she enrolled in Appalachian State University's Sustainable Technology and the Built Environment Masters of Science program with a concentration in Appropriate Technology. Ms. Wilmoth held two research assistantships with the Office of Sustainability and with the NEXUS integrated research team during her time at Appalachian State University. She also interned with Wine To Water for two semesters, where she gained experience in working with a WASH non-profit organization. She received her Masters of Science in May 2021.

Ms. Wilmoth is passionate about issues of food and water access, and she wants to work towards implementing sustainable and appropriate solutions to improve global living standards.