Evaluation of the Complementary Use of the Ceramic (*Kosim*) Filter and Aquatabs in Northern Region, Ghana

By

Andrew A. Swanton

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ABSTRACT

The *Kosim* filter is a ceramic water filter that is currently used in Northern Ghana. Based on prior MIT research in Northern Ghana, this technology is effective at removing 92% of turbidity, 99.4% of total coliforms, and 99.7% of *E. Coli* from unimproved water sources. However, the product water is still microbially contaminated. The purpose of this thesis is to explore the effectiveness of combining two household water treatment technologies, the *Kosim* filter and Aquatabs, in order to achieve a more effective and complete water treatment system. Aquatabs are sodium dichlorisocyanurate chlorine tablets that are used on the household scale. They are particularly effective at killing pathogenic bacteria; however, they have predominantly been applied in emergency relief situations and have never, apart from one research study conducted by the Center for Disease Control, previously been applied in Ghana.

In this study, 59 rural households (24 in a lower-class community and 35 in a lower middle-class community) in possession of *Kosim* filters were visited as part of a three week pilot study. During the initial visit, households were surveyed about the use and perception of their *Kosim* filters, they were trained in the use and given a one week supply of Aquatabs, and their *Kosim* filtered water (without Aquatabs) was tested. After one week, the same households were re-visited. A similar survey was conducted about the use and perception of the combined *Kosim* filter and Aquatabs system, and the filtered and chlorine disinfected water was tested.

The addition of Aquatabs to the *Kosim* filtered water significantly reduced the microbial contamination; however, it did not completely remove pathogenic bacteria. The average total coliform concentration in the drinking water was reduced by 50% compared to the filtered-only water, and the percentage of households with no total coliform concentration increased from 44% to 64%. Furthermore, the percentage of households with no *E. Coli* in their drinking water increased from 88% to 98%. In terms of user acceptability, all of the survey respondents indicated that the Aquatabs "improved the taste of the water" as they associated it with municipally treated or bottled water, suggesting that the chlorine taste is acceptable to these potential consumers.

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Title: Senior Lecturer of Civil and Environmental Engineering

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LIST OF ABBREVIATIONS

CFU	Colony Forming Unit
CS	Colloidal Silver
CTL	Ceramica Tamakloe Ltd.
CIA	Central Intelligence Agency
EC	Escherichia Coli
FAC	Free Available Chlorine
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GHC	Ghana Cedi
GSS	Ghana Statistical Service
GSB	Ghana Standards Board
HWTS	Household Drinking Water Treatment and Safe Storage
ICAITI	Central American Research Institute for Industry
IMF	International Monetary Fund
JMP	Joint Monitoring Program
MAP	Medical Assistance Programs
MCL	Maximum Contamination Level
MCLG	Maximum Contaminant Level Goal
MDG	Millennium Development Goals
MEng	Master of Engineering
MIP	Mercury Intrusion Porosimetry
MIT	Massachusetts Institute of Technology
MPN	Most Probably Number
NGO	Non-Government Organization
NPV	Net Present Value
NTU	Nephelometric Turbidity Units
PFP	Potters for Peace
PHW	Pure Home Water
STDV	Standard Deviation
TC	Total Coliform
UN	United Nations
UN-DESA	United Nations Department of Economic and Social Affairs
UN-NGLS	United Nations Non-Governmental Liaison Service
UNICEF	United Nations Children's Fund
US	United States
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

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1.0 Introduction and Background

1.1 Urgency for Clean Water

Statistics from 2004 indicate that 1.1 billion people currently lack access to an improved water supply. Improved water supply is defined by the Joint Monitoring Program (JMP, a collaboration of the World Health Organization (WHO) and the United Nation's Children's Fund (UNICEF)) as the availability of at least 20 L of water per person from an improved water source within 1 km of that person's dwelling (WHO/UNICEF, 2007). Improved water sources include protected springs, boreholes, household standpipes, etc., which provide safe, clean water. Further, the majority of these 1.1 billion people reside in either Asia or Africa, with 2 of 5 Africans lacking access to an improved water supply.

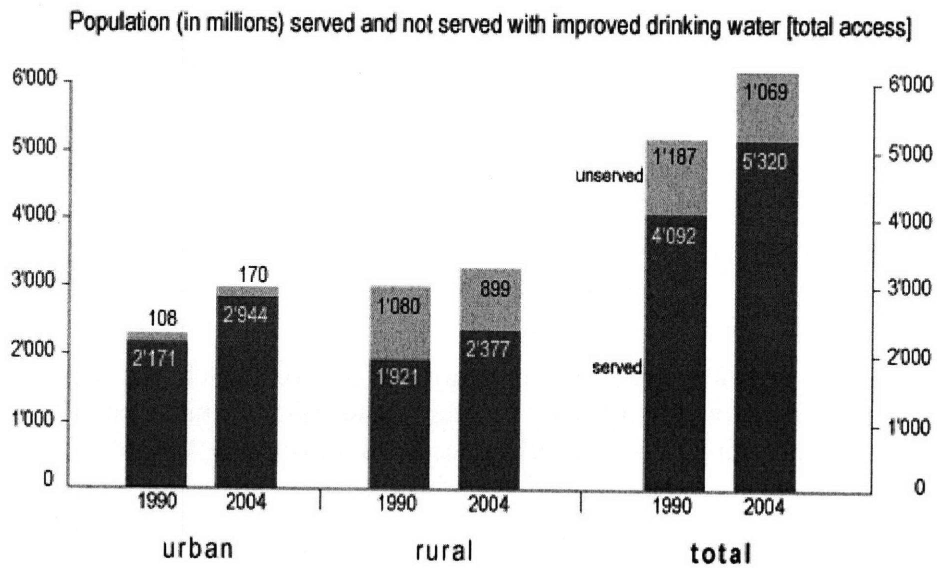


Figure 1: Distribution of the world population with and without access to an improved water supply in urban and rural areas in 1990 and 2004 (WHO/UNICEF, 2007).

Figure 1 indicates that the percentage of people with access to an improved water supply has risen from 78% in 1990 to 83% in 2004. While this shows an improvement, 17% of the world's population is still in need. Furthermore, 1.3 to 2.0 billion people are currently without access to safe drinking water (water that is below government water quality limits) (Smith, 2008).

Waterborne diseases (diarrhea, typhoid, etc.) are just one of the many effects of this glaring issue. Currently, there are four billion cases of diarrhea per year worldwide, resulting in 1.8 million deaths (90% of which are amongst children under five years old) (WHO/UNICEF, 2006). Furthermore, statistics show that 10 million people die each year from cholera, typhoid, dysentery and other diarrheal diseases caused by poor sanitation.

Members of the United Nations (UN) assembly met from September 6th-8th, 2000 to address these issues. The result was the development of the UN Millennium Development Goals (MDGs), a set of eight goals aimed at meeting the basic needs of the worldwide population. The seventh goal details the need to ensure environmental sustainability (UN, 2005). A subset of this goal, Target 10, is to reduce by half the proportion of people without sustainable access to safe drinking water by 2015 (UN-NLGS, 2007). A 2006 report released by the UN shows that there is still significant work that needs to be done to achieve this goal.

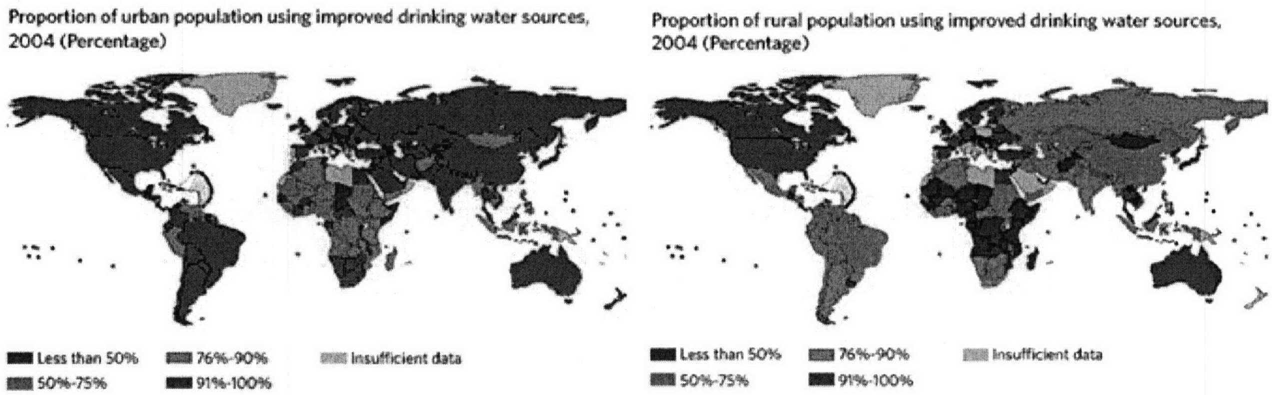


Figure 2: Percentage of the world population using improved water sources in urban and rural areas (UN-DESA, 2006).

Additionally, the 4th Millennium Development Goal is to reduce child mortality. Specifically, this goal aims to reduce by two thirds the child mortality rate amongst children under five. Seeing as how diarrhea accounts for roughly 1.6 million deaths among children under five, the eradication of this disease is important (UN, 2005). In order to do this, progress must be made to enhance water and sanitation in the developing world.

1.2 Ghana

1.2.1 Geography

The Republic of Ghana is located in Western Africa. It borders Togo to the East, Burkina Faso to the north, Côte d'Ivoire to the west, and the Gulf of Guinea to the south.

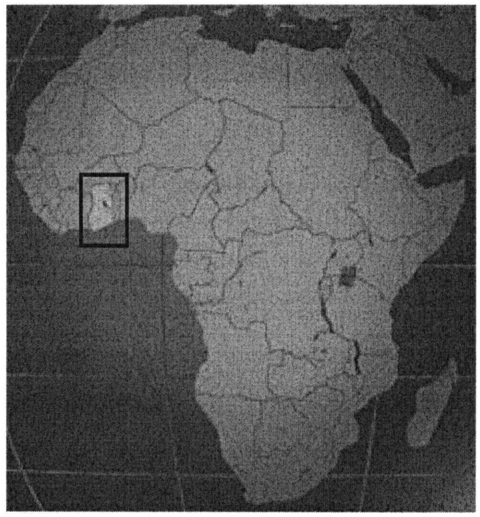


Figure 3: Geographical location of Ghana (FAO, 2007).

Ghana has a land area of 239,460 sq km, which is slightly smaller than the state of Oregon and roughly the same size as the United Kingdom (About, Inc., 2007). The climate is varied across the country, but primarily tropical. In the southeast it is warm and dry, contrasted by hot and humid conditions in the southwest. In the north, the climate is hot and dry (World Factbook, 2007). The rainfall trends are seasonal. In the south there are two rainy seasons; May-June and August-September (IMF, 2006). In the north there is just one rainy season, beginning in May or June and ending in September or October (BBC, 1997).

There are roughly 21 million people in Ghana, with a median age of 20 years (About, Inc., 2007). In 2007, the infant mortality rate was 54 deaths per 1,000 live births. This is a better rate than the countries neighboring Ghana: Burkina Faso, Côte d'Ivoire, and Togo have infant mortality rates of 90, 87, and 59 deaths per 1,000 live births, respectively (CIA, 2008). However, the infant mortality rate in Northern Ghana is 154 deaths per 1,000 live births (GSS, 2004). Additionally, Ghana joins many of its African neighbors as having one of the worst life expectancy rates in the world, 59 years (World Factbook, 2007).

1.2.2 Socioeconomic Status

Ghana has a number of valuable natural resources (namely gold, timber and cocoa). As a result, a large component of Ghana's economy is governed by foreign exchange. Despite these resources, a 1992 estimate indicated that 31.4% of Ghanians are below the poverty line (About, Inc., 2007).

A standard means of calculating a nation's worth is to sum the value of that nation's goods and services produced for one year. This calculation is what is known as the Gross Domestic Product (GDP). In 2006, the International Monetary Fund (IMF) calculated Ghana's GDP to be US $59.4 billion, compared to a GDP of US $13,020.9 for the US.

This places Ghana 74th out of the 179 nations assessed in 2006. Nations with similar GDPs include Guatemala, Uzbekistan, and Kuwait (IMF, 2006).

The distribution of wealth in Ghana is also of note. One statistic that measures the distribution of income is known as the Gini Index. If a country has perfect distribution (everyone makes the same amount of money) the Gini Index will be 0, where as if there is perfect inequality amongst incomes the Gini Index will be 100. The Gini Index for Ghana is 41 (Earth Trends, 2003). This is the same Gini Index as the US.

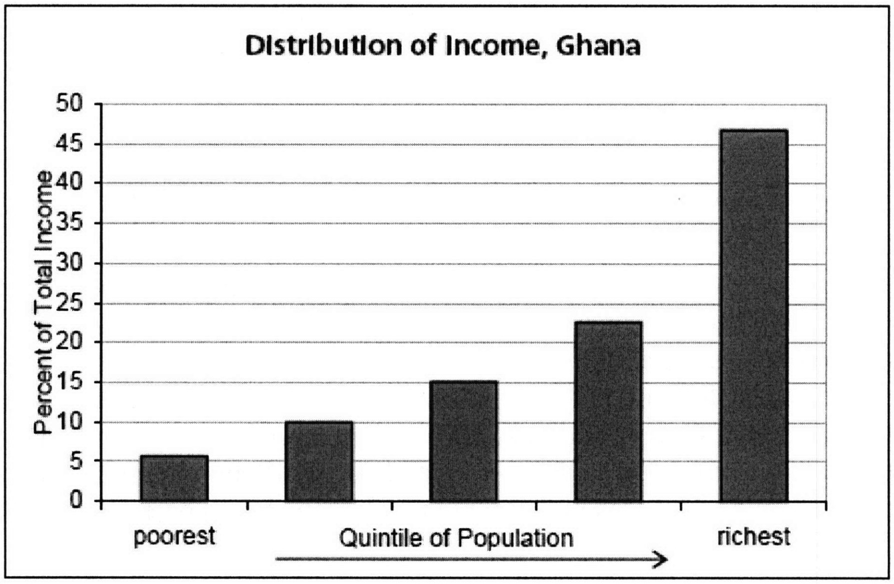


Figure 4: The Distribution of Income in Ghana among 20% quantiles (Earth Trends, 2003).

Additionally, 45% of the population lives on less than US $1 US per day and 79% of the population lives on less than US $2 per day (Earth Trends, 2003).

1.2.3 Water Quality in Ghana

Master of Engineering (MEng) MIT student Sophie Johnson conducted a survey in Northern Region, Ghana in 2007 that indicates that 0% of traditional households always have access to improved water or sanitation (Johnson, 2007). But among modern households, 83% always have access to an improved water source, and 100% always have access to improved sanitation. Traditional (rural) households are of mud-brick construction with thatch roofs and dirt floors. Modern (urban) households are of concrete or brick construction with concrete floors and tin or tile roofs. Another study reports that 88% of urban populations are using improved drinking water sources, compared with only 64% of rural populations (UNICEF, 2004). Table 1 shows the state of water and sanitation in Ghana in 2000, and what the MDG's aim to achieve by 2015.

Table 1: Water and Sanitation in Ghana in 2000 Compared with MDG Targets for 2015 and 2020 (Ampomah, 2004)

		2000			MDG - 2015		
		Pop (m)	Access (m)	Access (%)	Pop (m)	Access (m)	Access (%)
Water (MDG 2015)	Rural	11.8	5.2	44%	17.1	12.5	73%
	Urban	8.4	5.1	61%	13	11.4	88%
	Total	*20.2*	*10.3*	*51%*	*30.1*	*23.9*	*79%*
Sanitation (MDG 2020)	Rural	11.8	1.3	11%	19.3	10.8	56%
	Urban	8.4	3.4	40%	15.1	12.1	80%
	Total	*20.2*	*4.7*	*23%*	*34.4*	*22.9*	*67%*

Table 2: Progress Made Towards Meeting MDGs in Ghana, Mali, and Niger (Ampomah, 2004)

Country	Goal 1 Eradicate extreme poverty and hunger	Goal 4 Reduce child mortality	Goal 7 Ensure environmental sustainability	
	Target Halve the proportion of people suffering from hunger	Target Reduce under five and infant mortality rates by two-thirds	Target Halve the proportion of people without sustainable access to improved water and basic sanitation	
	Undernourished people (as % of total pop)	Under-five mortality rate (Per 1,000 live births)	Population with improved access to water sources (%)	Population with improved access to basic sanitation (%)
Ghana	On track	Off track	Off track	Off track
Mali	Off track	Off track	On track	Off track
Niger	Off track	Off track	Off track	Off track

It is clear from Table 2 that if the conditions continue to progress in the same manner as they have to date, the MDG targets for improved access to water and basic sanitation (among others) will not be reached for Ghana.

1.2.3.1 Microbial Contamination

In the WHO's Guidelines for Drinking Water Quality, the first priority for drinking water is to "ensure an adequate supply of microbially safe water" (WHO, 2004).

The presence of pathogenic bacteria in drinking water is typically due to fecal contamination. However, it is generally difficult to measure fecal contamination. As a result, non-pathogenic and easily detectable microorganisms are used as indicators of fecal contamination in drinking water. One means of doing this is to measure the total coliform (TC) count. Coliforms are among the 1% of bacteria that are capable of forming colonies. TCs are non-pathogenic, but their presence indicates microbial contamination. The standard unit of measure for reporting TC contamination is the total number of colony forming units (CFU) per 100 mL. The EPA approved the use of TC as a microbial indicator in 1986 when they passed the Safe Drinking Water Act (Gallagher, 1996). The WHO Guidelines for Drinking Water Quality 3rd Edition (2006) refers to TC as appropriate for evaluating drinking water treatment system performance (WHO, 2004). The Ghana Standards Board (GSB) requires that TC concentrations in drinking water be 0 CFU/100 mL (GSB, 1998).

Another means of measuring bacterial contamination is to measure the *Escherichia coli* (EC) count. EC is a bacteria present in feces. In human defecate there may be as many as 10 trillion EC bacteria microorganisms. Due to EC's origin in feces, the presence of EC has typically been used to indicate fecal contamination of water sources. EC concentration is a subset of the TC concentration, so according to the GSB, there should be 0 CFU/100 mL of EC present in drinking water.

MIT Master of Engineering (MEng) students Rachel Peletz and Sophie Johnson conducted an epidemiological study on water quality conditions in Northern Region, Ghana in 2006 and 2007, respectively. During the study, both students took water samples from a combination of traditional and modern households. The drinking water sources among the households surveyed included household taps, standpipes, boreholes, and dugouts. In Peletz's research, the primary and secondary drinking water sources were boreholes and dugouts, respectively. From 24 samples, 100% tested positive for TC, with an average TC concentration of 3,000 CFU/100mL (Peletz, 2006). Peletz's results also show that 71% of the samples taken tested positive for EC, with an average of 50 CFU/100mL. Johnson's research indicated an average TC concentration of 23,000 CFU/100mL among traditional homes, which primarily used dugouts for water collection, and 1,500 CFU/100mL among modern homes, which primarily used household taps or standpipes for water collection (Johnson, 2007). Similarly, Johnson's results indicate that the average EC count is 690 CFU/100mL in traditional homes, and 1.4 CFU/100mL in modern homes (Johnson, 2007).

1.2.3.2 Turbidity

Turbidity is a measure of the cloudiness of a water sample, as a result of suspended and colloidal solids. This cloudiness originates from phytoplankton, resuspension of sediments, urban runoff, sediments from erosion, algae growth, and waste discharge. The reason that high levels of turbidity is a health concern is that contaminants like bacteria and virus attach to the particles. Once the bacteria or virus attaches to the particles, it is more difficult to disinfect the water via chlorination or other methods, because the solid acts as a shield for the contaminant.

A Nephelometer, also known as a turbidimeter, is an instrument for measuring suspended particulates in a liquid. It shines a light through a water sample and measures the intensity of light that scatters at a 90° angle from the source beam. The more suspended solids in the water sample, the more scattering, and the higher the turbidity. Units are recorded in Nephelometric Turbidity Units (NTU). Another means of measuring turbidity that is particularly useful in remote field settings is with a turbidity tube. Using a turbidity tube, the turbidity is reported in Turbidity Units (TU). The GSB sets a maximum turbidity in drinking water of 5 NTU (GSB, 1998). A turbidity of 5 NTU represents the point at which the turbidity becomes visible to the naked eye (WHO, 2004). The WHO does not set a guideline for the maximum turbidity level, however, a value of 0.1 NTU is recommended for disinfection purposes (WHO, 2004). As a basis of comparison, as of 2002 the US water quality standard for turbidity is a maximum of 1 NTU. Additionally, 95% of the daily samples must not exceed 0.3 NTU in any given month (USEPA, 2005).

In Northern Region, Ghana, 1 million of the 1.8 million people drink water from unimproved sources, one of the most common of which is dams (or dugouts) (GSS, 2004). Dams are excavated, structures, which store water that precipitates during the rainy season and that flows from intermittent streams. Some of these dams dry out due to the long duration of the dry season (9 months), forcing community members to travel long distances to collect water from other sources.

A major health concern associated with these dams is that they are highly turbid. Harvard School of Public Health Masters student Melinda Foran performed turbidity tests on eleven dams during the rainy season in 2007. The average turbidity value of the dams tested was 690 TU, with a median of 300 TU (Foran, 2007). Additionally, some of the dams had turbidity values as high as 2,000 TU. These turbidity tests were performed at the dams themselves, so there was no time for the particles to settle. MIT MEng student Johnson performed turbidity tests on stored, pre-treatment water samples during the dry season (2007). Because these samples were taken from household storage containers, the time that passed between water collection and sampling likely allowed the settling of particles. From 33 different rural households, which primarily used dams as their water source, Johnson calculated an average turbidity of 190 NTU (Johnson, 2007).

Table 3: Average Turbidity of Dams in Northern Region, Ghana (Foran, 2007, Johnson, 2007)

Season	Sampling Location	Number of Samples	Average Turbidity
Rainy	Direct From Dams	11	690 TU
Dry	Storage Containers in Households	33	190 NTU

1.2.3.3 Diarrhea

Because many of the primary water sources in Northern Region, Ghana are unimproved and microbially contaminated, Peletz investigated the correlation between the use of improved water sources and the prevalence of diarrhea. Among households surveyed where at least one person had diarrhea, 10% of people had diarrhea, while of those same households only 47% always used improved water sources. On the other hand, among household where there was no diarrheal disease, 74% of those households always used improved water sources (Peletz, 2006).

1.3 The *Kosim* Filter

The ceramic pot filter is locally manufactured in Ghana by Ceramica Tamakloe Ltd. (CTL) and distributed in the Northern sector of Ghana by Pure Home Water (PHW). Locally branded the *Kosim*[1] filter by PHW, this ceramic water filter is impregnated with colloidal silver. It relies on gravity to filter water through porous clay and is shaped in the form of a flower pot. It is 31 cm in diameter, 24 cm high, and holds 8-8.5 L of water when full (Jackson and Murcott, 2007). The top of the filter rests on a plastic ring that fits on top of the plastic storage receptacle, which the filtered water is collected in. The storage receptacles are 50 L clear, plastic buckets. Some advantages associated with the use of plastic receptacles include ease of storage, shipping and handling, and cleaning. Other components of the filter unit include a plastic spigot connected to the bottom of the receptacle, and a plastic or ceramic lid for the top of the filter and receptacle.

[1] Kosim is a Dagbani word meaning “clean water”, “the best water” or “the water one serves to guests”

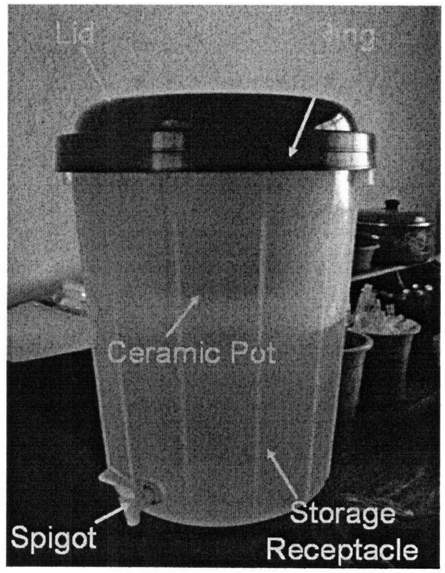


Figure 5: The *Kosim* Filter and its components (PFP, 2007).

The ceramic filter is made in Ghana, while the storage receptacle, lid, ring and spigots are imported. The sales and distribution of *Kosim* filters in Northern sector of Ghana, as well as in Burkina Faso is carried out by PHW. PHW has three full-time and two part-time employees who are responsible for contacting communities, making community presentations, and selling the *Kosim* filters to consumers in the North. For rural sales, when PHW contacts a new community to sell *Kosim* filters, they first contact the village chief and/or the village volunteer. Each community has a village volunteer, who is responsible for keeping records of the people in the community, organizing village events (feasts for newborns, funerals, etc.), and other tasks. This meeting leads to a community wide demonstrative training about the use of the *Kosim* filter, which is led by a PHW information, education and sales specialist. The specialists are native to this particular region and speak the local language. After the presentation, the village volunteer gathers a list of all the people who want to purchase a filter. They are also responsible for collecting money for the filters. In return, the village volunteer is rewarded with a Ghana Cedi (GHC) 1 (equivalent to US $1) commission for the sale of each filter. Once a list has been created and the appropriate money collected, filters are delivered to the communities.

In Nicaragua, 15% of ceramic pot filters—of identical design by Potters for Peace (PFP)—that were monitored over a six month span incurred breakages (Hwang, 2003). Studies on similar filters in Cambodia have identified a 2% ceramic filter disuse rate per month, mostly due breakages (Brown, 2007). According to PHW, it is recommended that *Kosim* filters be replaced every three years (Jackson and Murcott, 2007).

Peletz's and Johnson's research determined the effectiveness of the *Kosim* filter at mitigating diarrhea in Northern Region, Ghana. Peletz determined that the use of the *Kosim* filter reduced the risk of diarrhea by 42% for children under five (Peletz, 2006). Johnson found that households with filters were 69% less likely to have diarrhea when compared to households without filters (Johnson, 2007). In Cambodia, the ceramic filters reduced diarrheal rates among users by 40% when compared with non-users (Brown and Sobsey, 2007).

1.3.1 History

In 1981, the InterAmerican Bank funded a research study to determine the most efficient and sustainable filter (ICAITI, 1984). The filters were judged by their flow rate, their effectiveness at removing bacteria, their cost, their ease of distribution, and whether they could be locally made. One of the groups receiving funding for this study was the Central American Research Institute for Industry (ICAITI). Dr. Fernando Mazariegos worked for the ICAITI and was the first to develop a colloidal silver impregnated ceramic pot filter. Mazariegos' filter was handmade and was effective at treating microbially contaminated waters (ICAITI, 1984). His filter was also cost-effective and easily produced. In 1984, Mazariegos received funding from the United States Agency for International Development (USAID) to work with Medical Assistance Programs (MAP) International to spread the colloidal silver ceramic filter design to Quechua potters in Cotopaxi, Ecuador (MAP International, 1985).

In 1994, after Guatemalan communities rejected the use of chlorine tablets, AFA Guatemala investigated using Mazariegos' filter technology as an alternative. They conducted a one-year study that indicated that using the ceramic pot filter reduced the incidence of diarrhea by 50% (Donachy, 2004). Later, in 1998, Hurricane Mitch devastated drinking water sources across Central America, which affected an estimated 18% of the population in Nicaragua (USAID 2001, 2001a). This disaster created a need for a simple, low-cost, mass-produced, water treatment technology. In response, Potters for Peace (PFP) standardized the shape and size of Mazariegos' filter and began mass-producing them for implementation in 1999 (Rivera, 2008).

Since then, the PFP filter—originally designed by Mazariegos—has reached 1.5 million users in 21 countries across the world in Central America, the Caribbean, West Africa and South East Asia (Rivera, 2008). To accomplish this, approximately 30 locally owned and operated filter manufactures have been established in these areas of the world. The PFP filter is commonly known as the *Filtron* in Central America and by various other brand names in specific countries. In Ghana, it is known as the *Kosim* filter.

1.3.2 Use

To use the *Kosim* filter, all one must do is fill the ceramic pot-shaped filter with water and allow gravity to perform the filtration. One must ensure that the lid to the ceramic filter is always on so that the water is not contaminated by airborne particles or unhygienic handling. While the actual use of the filter is simple, there are specific instructions for cleaning. The filter itself must be scrubbed frequently with filtered water to remove filtered particles and microbes. In Northern Ghana, it is recommended that filters be cleaned after each use. Also, the inside of the storage receptacle should be cleaned with chlorine once a month. (Instructions provided by PFP for use and maintenance of the filter are provided in Appendix A.)

1.3.3 Ceramic Filter Composition and Production

The primary components of the *Kosim* filter are clay, water, and combustible material. Typical PFP filters are composed of 50% clay and 50% combustible material, although proportions vary (PFP, 2008). Sometimes grog/temper is added to the mixture in order to control shrinkage and avoid cracking (Dies, 2003). Initially, clay of a particular grain size is gathered, it is mixed with water, and then combustible material is added to the mixture. This order is important to ensure that clay is the material which absorbs the water.

After the mixture has been properly combined, aluminum filter molds are used to form the shape of the filter. Hydraulic presses are often used, but a variety of methods have been employed in practice. After forming, the filters are left to dry for 2-3 days (PFP, 2008). This is important to ensure that the pots do not crack due to rapid drying. The next step is to fire the pots in kilns at a temperature of 887°C (PFP, 2008). During firing the heat removes any additional water, chemicals are oxidized, the clay vitrifies, and the sawdust is burned off, leaving pores in the ceramic. Afterwards, the filters are allowed to cool, and the filter flow rate is tested. If the filters are within the 1-2.5 L/hr specified flow rate, colloidal silver is painted on the filter or it is dipped in a bath of colloidal silver.

To encourage widespread use, there is no patent on the PFP filter (PFP, 2007).

1.3.3.1 Clay

Clay is a naturally forming material that results from the weathering of rocks. It has a high plasticity, which means that it is easily workable. This property is significant as it allows ceramicists the ability to manipulate clay into certain shapes. The clay used in ceramic filters is typically earthenware clay. Earthenware clays differ from stoneware and porcelain clays in that it is more porous, it is the most commonly found in nature, and it has the lowest firing temperature (Shepard, 1968, Dies, 2003).

In order to use the earthenware clay, it first must be dried by air drying, fan drying, or other methods. The clay is then sieved to a certain grain size by using screens with openings of specified size. As a result, each screen has a maximum grain size associated with it; given by the number of openings in one square inch (e.g. 60-mesh screens have 60 openings per square inch). For PFP filters, the clay must be sieved between 60-mesh and 35-mesh screens, resulting in clay with a grain size between 0.42 mm and 0.73 mm in diameter (PFP, 2007).

1.3.3.2 Combustible Material

Combustible materials are important in the production of ceramic filters as they create the porosity of the filter after incineration. In this application, combustible materials can be sawdust, corn flour, wheat flour or rice husk. Typically, PFP filters are composed of sawdust. The combustible material is sieved through 300-mesh screens (particles with a grain size less than 85 μm in diameter) before being added to the mixture.

1.3.3.3 Pore Size

In ceramic pot production, the pore size is of the utmost importance. If the pore size is too large, then bacteria will pass through the filter. On the other hand, if the pore size is too small, the flow rate will decrease beyond a useable limit. Bacteria have a size range from 0.3 to 100 μm, viruses have a size range between 0.02 and 0.2 μm (MEI, 1991), and protozoa have a size range from 5 to 500 μm (American Society of Microbiology, 2006). If the ceramic filter was designed to remove all of these germs, it would not yield a sufficient flow rate. Therefore, the ceramic filter is designed to only filter bacteria and protozoa. The most important, measurable bacteria are EC. EC are rod shaped bacteria, with a 2 μm length and a 0.5 μm width. According to PFP, pore size should be no larger than 1 μm in order to effectively remove EC (PFP, 2008). However, maintaining this minimal pore size would negatively affect the flow rate. As a result, the pore size is typically designed larger and colloidal silver (CS) is added to prevent EC from filtering through (discussed more thoroughly in the following section).

An electron microscope was used to determine that typical PFP ceramic filters in Nicaragua have pores that range from 0.6-3 μm (Lantagne, 2001). Further tests were performed by Doris Van Halem on filters from Nicaragua, Cambodia, and Ghana using two different methods, bubble-point test and MIP (Van Halem, 2003). Using the bubble-point test, the average pore size was 40 μm, and using mercury intrusion porosimetry (MIP), pore lengths varied from 16 to 25 μm. With Ghanian made filters, Van Halem's research identifies pore sizes of *Kosim* filters to be 40 μm and 19 μm using the bubble-point test and the mercury intrusion test respectively.

The reason that these tests may differ is because compositional properties of filters may be different. As mentioned in the previous two sections, clay and sawdust are sieved within a particular grain size range. Therefore, some filters may be composed of particles that are on the lower end of that range, while others may be composed of particles that are on the upper end of that range. As a result, the pore sizes of the different filters would be variable.

With the pore sizes described above, some of the bacteria would be filtered, but a significant portion would pass through if screening were the only process removing bacteria. However, it should be noted that other water treatment processes are taking place (e.g. sedimentation, diffusion, inertia, turbulence, and adsorption). Furthermore, CS is included in the design of the filter to kill bacteria.

1.3.3.4 Colloidal Silver

CS is a solution of water or proteins that contains submicroscopic particles of silver (.015-.005 microns) held in liquid suspension. The silver concentration used for PFP filters is 3.2% strength (3200 mg/L) Microdyn solution (Lantagne, 2001). Two milliliters of this solution is mixed with 200-300 mL of water and of the resulting solution, two-thirds is painted on the inside of the filter and one-third on the outside of the filter (Dies, 2003). This is done because studies have shown that water filters primarily through the sides of the filter, as opposed to the bottom (Lantagne, 2001). This is likely due to the fact that the porosity is lowest in the middle of the filter (42.5%) compared with the bottom (38%) (Van Halem, 2003). Once the silver has been applied, it seeps into the ceramic filter and distributes throughout the thickness of the sides. Studies have shown that the addition of the CS does not affect the flow rate (Lantagne, 2001).

"Silver compounds are used widely as effective antimicrobial agents to combat pathogens (bacteria, viruses and eukaryotic microorganisms) in the clinic for public health hygiene" (Silver, 2003). The primary reason for adding colloidal silver to the ceramic filter is to control the growth of microorganisms. Silver accomplishes this by reacting with the structural groups and proteins in the bacterial cell, producing structural changes in bacterial cell membranes, and interacting with nucleic acids (Russell, 2004).

Lantagne's laboratory research on three PFP filters concludes that filters with an appropriate flow rate and with colloidal silver remove 100% of TC, fecal coliform, and EC, as well as 94-100% of fecal streptococcus (Lantagne, 2001). She arrived at this conclusion by testing bacterial removal through the ceramic filter at varying CS concentrations.

Table 4: Bacterial Removal Rates with Varying Concentrations of CS (Lantagne, 2001)

	Bacterial Removal Rates				
Silver Applied	No silver	2 mL .0094%	1 mL 3.2%	2 mL 3.2%	5 mL 3.2%
TC	98	76	100	100	100
Fecal coliform	97	63	100	100	100
Fecal streptococcus	82	76	100	100	100

The most important aspect of these results is that 1 mL of colloidal silver at strength of 3.2% is required in order to remove 100% of the three indicator bacteria.

Given that a metallic solution is added to the water filtration process, it is important to understand the associated health risks. The WHO guideline for silver in filtered drinking water is 0.1 mg/L or 100 μg/L (WHO, 1993). Field results from 24 homes in Nicaragua show that the concentration of silver in water filtered through PFP filters does not approach this limit (Lantagne, 2001a). Only two of the 24 households tested indicated a silver concentration greater than 5 μg/L (the two households had concentrations of 6 and 15 μg/L).

1.3.4 Flow Rate

Prior to distribution, the *Kosim* filters are tested for flow rate by the manufacturer in Accra, Ghana. If the flow rate does not fall within the range of 1-2.5 L/hr, the filter is discarded (Jackson and Murcott, 2007).

Table 5: Flow Rate of PFP Filters

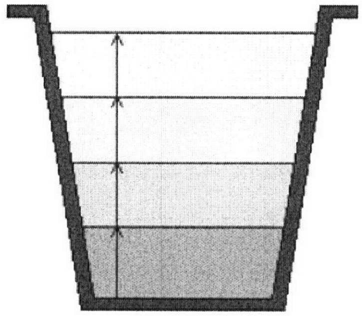
Location	Source	Number of Filters	Lab/Field	Range (L/hr)	Average (L/hr)
Ghana	Matellet, 2005	3	Lab	0.48 - 1.91	1.06
Ghana	Van Halem, 2006	7	Lab	1.05 - 4.29	2.41
Nicaragua	Lantagne, 2001	24	Field	0.13 - 3.5	0.98
Nicaragua	Van Halem, 2006	7	Lab	0.51 - 1.45	0.85
Cambodia	Van Halem, 2006	8	Lab	0.51 - 1.14	0.73
Cambodia	Brown, 2007	1	Lab	1.5 - 2	1.75
Burkina Faso	Piaskowy, 2008	2	Lab	0.16-3.37	0.61
Guatemala	ICAITI, 1984	1	Lab	N/A	3.5

When the WHO performs exposure calculations, they typically assume that each person consumes two liters of drinking water per day (Smith, 1998). Therefore, this standard can be used as an average for drinking water consumption.

Matellet calculated the flow rate through the *Kosim* filter in Northern Ghana applying water samples from various improved and unimproved water sources and determined that the flow rate ranged from 0.48 L/hr to 1.91 L/hr (Matellet, 2006). She calculated the flow over a three-hour span, and determined that the rate decreased each hour (from 1.84 L/hr to 0.83 L/hr to 0.52 L/hr) with an average flow of 1.06 L/hr. This gradual decrease is logical given the gravity-driven process of the ceramic pot filter. Assuming the *Kosim* filter is able to maintain a flow of 1.06 L/hr, 25 L of water would be available per day. This is enough water to provide two liters of drinking water for each person in a 12 person household (median household size in Northern Ghana, Johnson, 2007).

On the other hand, Lantagne conducted a field study that visited 24 Nicaraguan homes using the ceramic pot filter, and found that the flow rates ranged from 0.13-3.5 liters per hour. She concluded that 14 of the 24 filters did not provide a filtration rate sufficient to provide each family member with 2 liters of drinking water per day (Lantagne, 2001).

Furthermore, the exponential decrease in flow rate with time shown in Matellet's results has been observed elsewhere. Van Halem performed flow rate tests on PFP filters that were at full capacity, ¾ capacity, ½ capacity, and ¼ capacity.



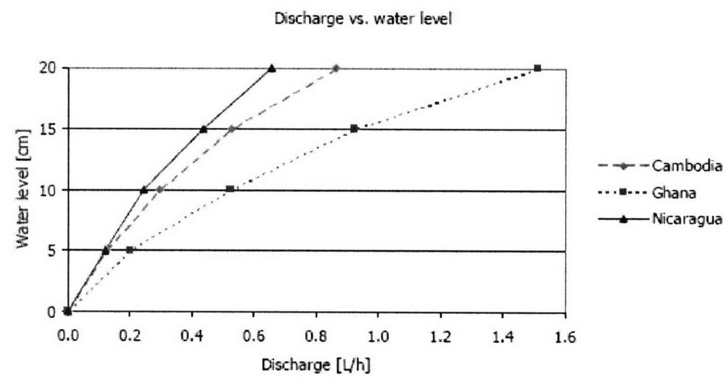


Figure 6: Average flow rate through PFP filters at different capacities (Van Halem, 2006).

Another means by which the flow rate is reduced is as a result of clogging over time. A study in 1984 found the flow rate through a ceramic filter to reduce by 50% (3.5 to 1.97 L/hr) over a one-year period (ICAITI, 1984). Additional studies indicate that after 12 weeks all discharges are reduced below 0.5 L/hr (Van Halem, 2003). This value is insufficient to provide improved water to a household.

The primary reason for reduced flow rates is due to the accumulation of particles (bacteria, suspended solids, etc.) that clog the pores in the filter. In Lantagne's 2001 study, all of the families cleaned the filter monthly, but not all of them cleaned them properly. In order to clean the filters properly, one must scrub the filter with enough force to remove the suspended solids. This scrubbing will also remove a microlayer of the ceramic; however, the filter is thick enough that these losses are inconsequential (Lantagne, 2001).

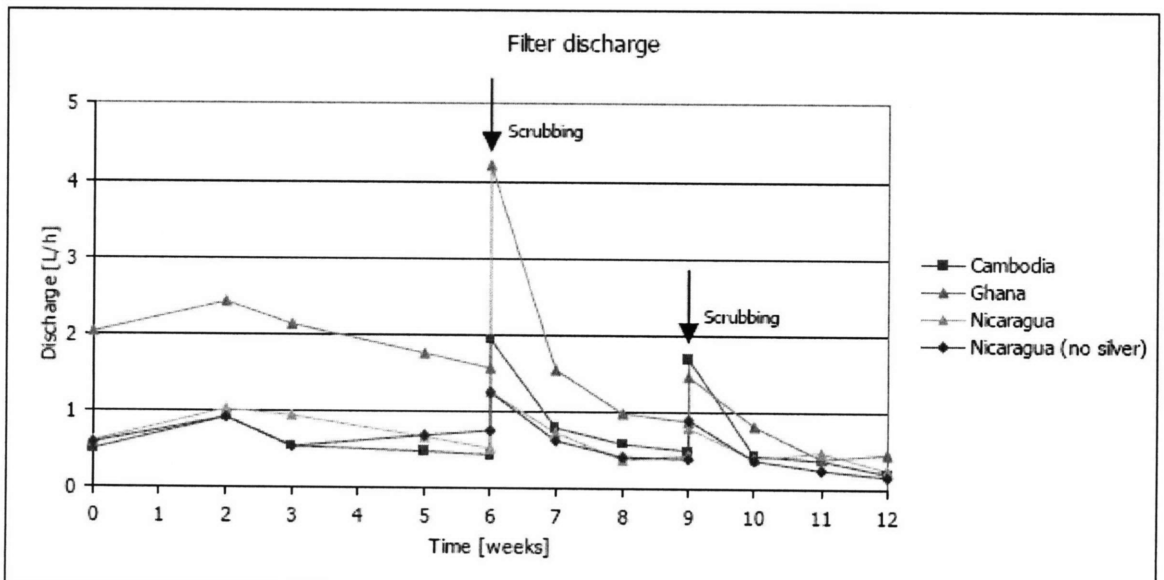


Figure 7: Average flow rates of PFP filters from Cambodia, Ghana, and Nicaragua over a 12 month span (Van Halem, 2006).

The importance of cleaning is further emphasized by Joe Brown's research. Figure 8 shows the viral removal through a ceramic filter. The steady decline in removal is noteworthy, as is the increase in removal after cleaning.

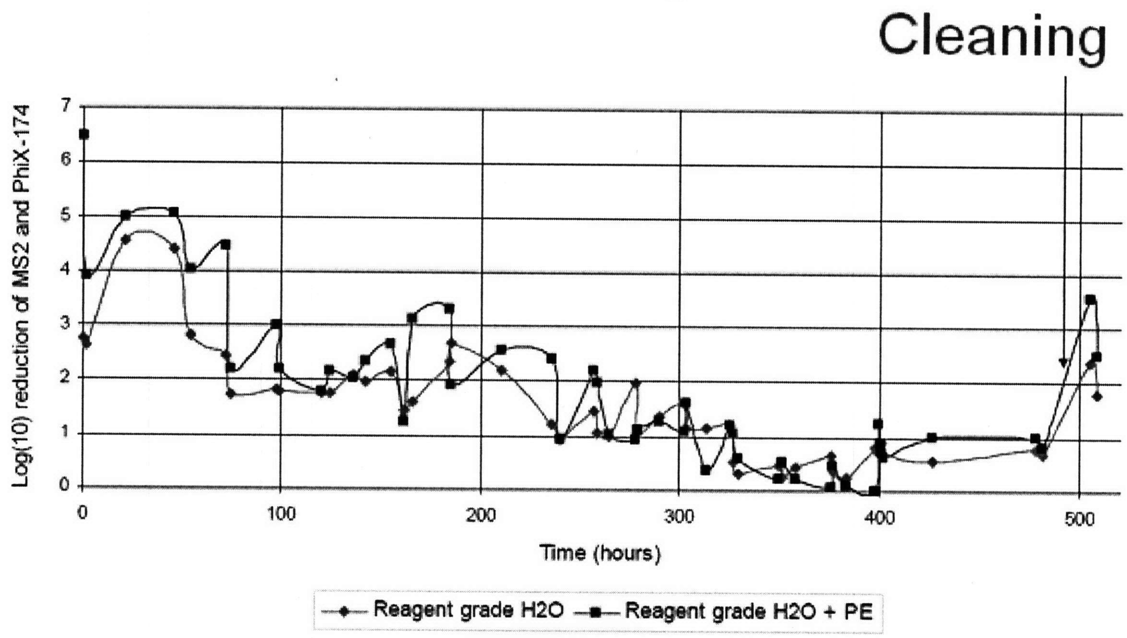


Figure 8: Viral removal rate of ceramic filter and the affect of cleaning (Brown and Sobsey, 2007).

Figure 7 and Figure 8 show the dramatic effect that cleaning has on regenerating flow rate. Lantagne was able to acquire two dirty filters from homes in Nicaragua. These filters had flows of 0.40 L/hr and 0.28 L/hr (Lantagne, 2001, 2001a). After thoroughly scrubbing these two filters, the flow rates were regenerated to 2.1 L/hr and 2.0 L/hr, respectively.

Sara Piaskowy performed flow rate tests on two *Kosim* filters—made by CTL and sold to the NGO Helvetas in Burkina Faso by PHW—over a three month period in 2008. In the beginning of the experiment, the filters were filled two times per day, once in the morning and once at mid-day, with water with turbidity 8.63-16.37 NTU and fecal contamination 4,120-34,100 CFU/100mL (Piaskowy, 2008). As the study progressed, the filters were only filled once per day because the flow rate had slowed to a point where it was unnecessary to fill the filter again. Additionally, the filters were cleaned twice. The first cleaning was one month into the experiment and the filter was cleaned by scrubbing. The second cleaning was two months into the experiment and the filter was cleaned by both scrubbing and backwashing. To backwash the filter, Piaskowy filled a sink with "clean water" and placed the ceramic element in the tub upside down. She placed a tub on the ceramic element to keep it submerged and allowed gravity driven backwashing to filter water through the ceramic in the reverse direction as water is typically filtered. The addition of backwashing significantly helped regenerate the flow. The flow rate from one of these two filters is displayed below.

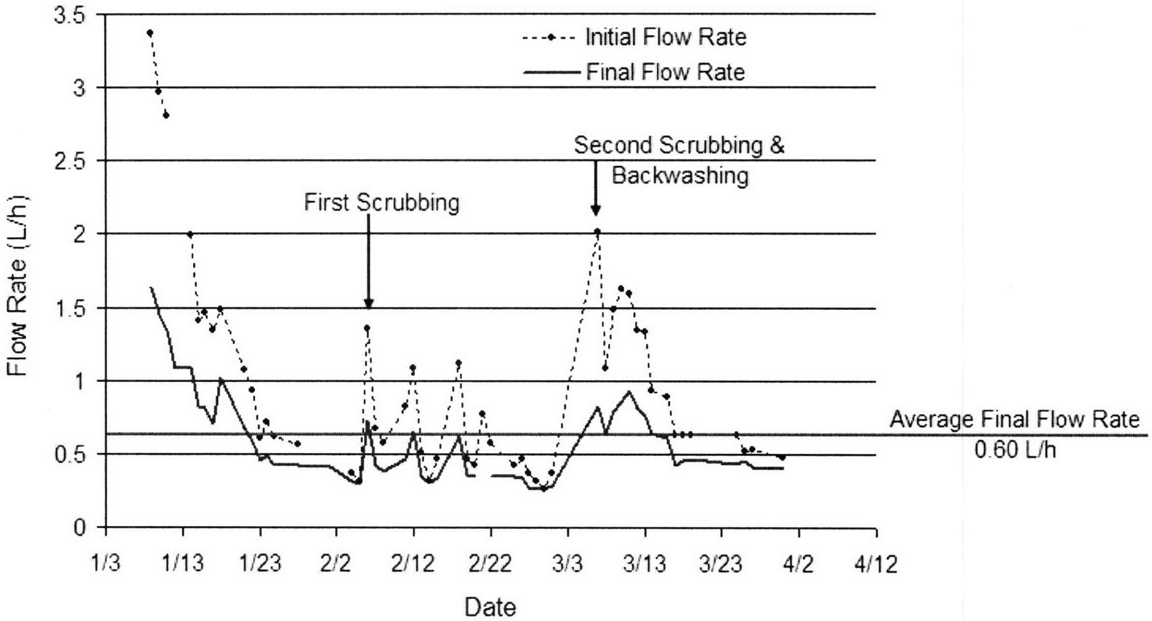


Figure 9: Prolonged flow rate through *Kosim* filter. The "initial flow rate" refers to the flow rate during the first hour. The "final flow rate" refers to the flow rate between the third and fourth hours of filtration (Piaskowy, 2008).

Lastly, research has shown that there is no variation in microbial performance among filters with flow rates between 1.0 and 2.1 L/hr (Lantagne, 2001).

Table 6: Microbiological Results in Three Filters with Different Filtration Rates (Lantagne, 2001)

	Raw Water	Factory Filtration Rate		
		1.0	1.5	2.1
Total Coliform	3108	0	0	0
Fecal Coliform	1583	0	0	0
Fecal Streptococcus	33	0	2	0
E. coli	0	0	0	0

1.3.5 Microbial Performance in Laboratories, Nicaragua, Cambodia, Ghana, and Other Locations

According to PFP, the ceramic filter technology should remove 99.98% of TC and EC under laboratory conditions (PFP, 2008). Extensive water quality tests have been performed in laboratories and in the field on filters produced in Nicaragua, Cambodia, and Ghana. The results from these tests are most often presented as the percent removal, log removal, the before and after microbial concentrations, or as the presence/absence of water quality indicators for TC, EC, and turbidity.

Table 7: Percent Removal of Water Quality Indicators for the PFP Ceramic Filter in Laboratory and Field Conditions

Research Specifics				Water Quality % Removal			
Location	Source	n[a]	Lab or Field	Turbidity	TC	EC	MS2[b]
Honduras	CESSCO, 1999	1	Lab		100		
Nicaragua	CIRA-UNAN, Aug 1999	8	Lab		99.9-100	100	
Nicaragua	CIRA-UNAN, Dec 1999	1	Lab		100		
Nicaragua	CIRA-UNAN, Jun 2000	1	Lab		98.9	100	
Nicaragua	CIRA-UNAN, Jun 2000	3	Lab		90-99.5	82-100	
Nicaragua	CIRA-UNAN, Jun 2000	3	Lab		100	100	
Nicaragua	CIRA-UNAN, Jul 2001	2	Lab		100		
Cambodia	Brown, 2007	1[c]	Lab			99.5	98
		1[d]	Lab			99.5	99
		2	Field			99.2	
Ghana	Matellet, 2006	3	Lab		99.5	100	
Ghana	Johnson, 2007	35[e]	Field	92	99.4	99.7	
		7[f]	Field	68	90	85	
Burkina Faso[g]	Piaskowy, 2008	2	Lab	87-100	98-100		

a – Number of filters
b – MS2 is a viral surrogate
c – Filter with colloidal silver
d – Filter without colloidal silver
e – Filters in traditional (rural) homes
f – Filters in modern (rural) homes
g—Filters were manufactured in Accra, Ghana by CTL

Table 8: Water Quality Values for the PFP Ceramic Filter Before (B) and After (A) Implementation

Research Specifics				Water Quality Values					
				Turbidity (NTU, TU)		TC (CFU/100mL)		EC (CFU/100mL)	
Location	Source	n[a]	Lab or Field	B	A	B	A	B	A
Bolivia	CESCCO, 1999	1	Lab			460	0		
Nicaragua	Lantagne, 2001a	24	Field			10	3.2		
Cambodia	Brown, 2007	60[b]	Field	7.52	3.08			3500	110
		80[c]	Field	8.70	1.53	14000	2000	2300	160
Ghana	Matellet, 2006	3	Lab			13167	60	0	0
Ghana	Peletz, 2006	24	Field			3000	0	50	0
Ghana	Johnson, 2007	35[d]	Field	190	11	23000	170	690	2.5
		7[e]	Field	4.5	1.4	1500	150	1.4	0.21

a – Number of filters
b – Randomized, controlled sample
c – Independent appraisal of filters sold from 2002-2005
d – Filters in traditional (rural) homes
e – Filters in modern (urban) homes

Table 9: Households Indicating Presence of Microbial Indicators Before and After Using the PFP Filter in Nicaragua (Lantagne, 2001a)

TC		EC	
Before	After	Before	After
24/24 = 100%	23/24 = 100%	15/24 = 63%	8/24 = 33%

Van Halem's results are presented as the number of samples that are within a particular range of percent removal for TC and EC. Therefore, these results are included in separate tables. The source water for the samples reported in Van Halem's research is from the Schie Canal in Delft, Netherlands.

Table 10: Laboratory Percent Removal of TC for Filters from Different Production Locations (Van Halem, 2006)

Country of origin	Percent removal				
	< 97%	97-97.99%	98-98.99%	99-99.99%	> 99.99%
Cambodia	0	0	3 (6%)	0	45 (94%)
Ghana	0	0	4 (8%)	3 (6%)	41 (85%)
Nicaragua	0	0	0	0	48 (100%)
Nicaragua (no silver)	0	3 (6%)	1 (2%)	3 (6%)	41 (85%)

Table 11: Laboratory Percent Removal of EC for Filters from Different Production Locations (Van Halem, 2006)

Country of Origin	n[a]	99%-99.9%	99.9%-99.99%	99.99%-99.999%	99.999%-99.9999%	99.9999%-99.99999%	99.99999%-99.999999%
Cambodia	10	1	1	1	5	2	0
Ghana	11	0	0	1	4	4	2
Nicaragua	12	0	0	1	1	6	4
Nicaragua[b]	8	2	1	3	2	0	0

a – Number of filters
b – Filters without colloidal silver

These results indicate that the PFP filter is effective at removing turbidity, TC, and EC. In terms of turbidity, the ceramic filter is able to reduce the turbidity of water sources on the order of 100's of NTUs to single digit turbidity values. The ceramic filter also typically removes greater than 99% of TC and EC. From the research presented in Table 7, TC concentrations in source waters are reduced by two orders of magnitude as a result of filtration (from 10,000's to 100's). Similarly, the EC concentrations are generally reduced by one order of magnitude (1,000's to 100's).

Lantagne gathered field data from 24 households concerning the performance of the PFP filter from Nicaragua in 2001. Turbidity levels decreased by 83% and 22 of the 24 samples were below the 1993 WHO guideline value of 5 NTU (WHO, 1997). Additionally, 98-100% of indicator bacteria were removed (Lantagne, 2001).

Van Halem conducted similar laboratory studies on the performance of a ceramic filter from Nicaragua in 2006. Van Halem proved that the ceramic filter impregnated with CS was able to reduce EC to less than or equal to 1 CFU/100mL (Van Halem, 2003). These values are contrasted with effluent EC concentrations from ceramic filters without CS of 10-29,000 CFU/100mL. Van Halem's research also found that the ceramic filter reduced turbidity counts from 0.8-31 NTU to 0.3 NTU.

Brown conducted extensive field and laboratory research on the reduction of microbial indicators with the ceramic filter in Cambodia. In terms of turbidity, Brown found that, on average, the ceramic filter reduced turbidity from 9.1 NTU to 2.6 NTU. He also found that the filters reduced EC by up to 99.9999%, with average removal rates of 99% in both field and laboratory testing (Brown, 2007). The filters also reduced the presence of viruses by 90-99%.

Matellet performed water quality testing with three ceramic filters on water samples taken from Northern Region, Ghana in 2006. Matellet found that the ceramic filters removed 99.5% and 100% of TC, using two Membrane Filtration and 3M™ Petrifilm™ test methods, respectively. Additionally, the filters removed 100% of EC (Matellet, 2006).

Johnson also performed water quality testing with the *Kosim* filter in 2007. In terms of turbidity, the ceramic filter removed 92% and 68% for traditional (rural) households and modern (urban) households, respectively. Her results also indicate that among traditional households the ceramic filter removed 99.7% of TC and 99.4% of TC (Johnson, 2007). Additionally, among modern households, removal rates were 85% of EC and 90% of TC. While these removal rates are significant, the treatment provided is not perfect. Traditional households with filters still had average TC count of 170 CFU/100mL, which indicates the *Kosim* filter is not capable of removing all TC.

1.3.6 Extent of Use in Ghana

The *Kosim* filter has already been widely distributed in Northern Region, Ghana. In 2004, funding was raised by a Dutch organization to bring filter ceramist expert, and PFP founder/director Ron Rivera to Ghana to train Peter Tamakloe and his employees to make the PFP filters (Matellet, 2006). Since then, Ceramica Tamakloe Ltd. (CTL) has been manufacturing filters and has sold 22,500 filters to date.

By 2006, CTL had grown to 35 employees and produced over 2,000 filters. The two primary organizations that purchase *Kosim* filters are Enterprise Works and PHW. Enterprise Works bought and distributed 10,000 filters between 2006 and 2007 (Stevenson, 2008) and PHW distributed 10,000 *Kosim* filters in the Northern sector of Ghana and Burkina Faso since CTL started manufacturing. UNICEF and Oxfam have bought 5,000 and 500 filters from PHW, respectively, in addition to the 2,000 already sold as of 2006 (Murcott, 2008). In January-March of 2008, PHW distributed roughly 2,000 filters to flood victims in the Upper East and Upper West regions of Ghana. CTL direct sales account for the remaining filters, which were likely sold in greater Accra.

The cost of a *Kosim* filter is GHC 15-20, which is approximately equal to US $15-20, depending on how far it must be transported and the level of training and service provided (Jackson, 2008). Urban retailers receive GHC 2, PHW salespeople receive GHC 1, and village volunteers receive GHC 1 commission for the sale of each filter. Additionally, it costs GHC 4.50 to replace the ceramic filter and GHC 2.00 to replace the tap (Jackson and Murcott, 2007).

1.4 Aquatabs

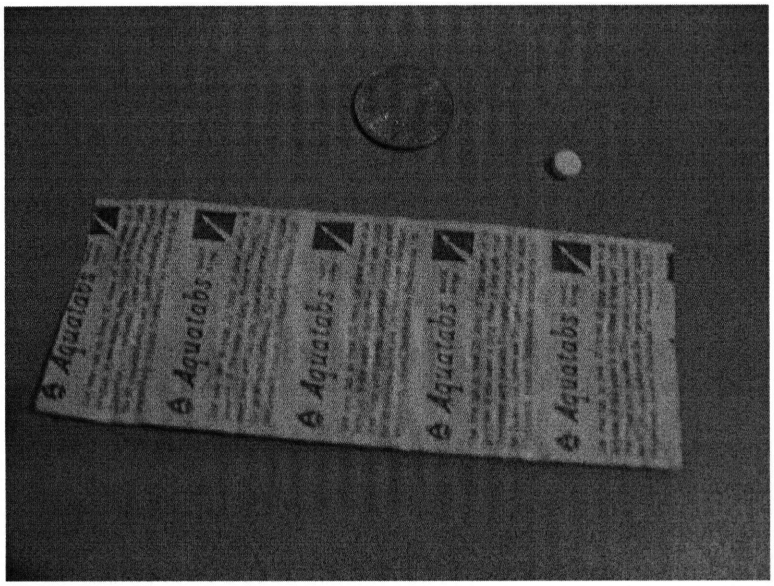


Figure 10: Strip of 10 Aquatabs.

Aquatabs are chlorine tablets that meet internationally recognized specifications for water treatment. The primary chemical constituent of Aquatabs is sodium dichloroisocyanurate (NaDCC or $C_3HC_{12}N_3O_3Na$), also known as sodium troclosene, triclosene sodium, or sodium dichloro-sy-triazine (Medentech, 2006). The two other primary constituents are adipic acid and sodium carbonate, which are added to maintain a constant pH in the water of 6.2 (Bakhir, 2003). This pH value ensures optimal conditions for the NaDCC to release a measured dose of hypochlorous acid (HOCL, which is referred to as the free available chlorine (FAC) level in this thesis) (Zen Backpacking, 2005). HOCL is electrically neutral, which allows for ease of diffusion through cell walls. After passing through the cell wall, the HOCL reacts with the proteins, DNA, RNA, fatty acid groups, cholesterol, or enzyme systems of the cell, which inactivates the bacteria.

Table 12: Chemical Composition of Aquatabs by Weight (Medentech, 2001)

Ingredient	Weight in Product (% w/w)
Troclosene Sodium / 1,3,5 - Triazine - 2,4,6 (1H, 3H, 5H) - trione, 1, 3 - dichloro-, sodium salt CAS No. 2893 - 78 - 9	39.41%
Adipic Acid CAS No. 000124-04-9	26.71%
Sodium Carbonate CAS No. 000497-19-8	6.00%

The tablets come in a variety of sizes and readily dissolve in water without leaving any deposits. They are used as a point-of-use water treatment, meaning they are applied directly to the water source, for emergency relief and routine household water disinfection (Da Vinci, 2006). In the past, Aquatabs have been supplied to the following International Aid Agencies: WHO/PAHO, UNICEF, Red Cross Organizations, Medicines Sans Frotieres, CARE, ECHO, and World Vision (Medentech, 2006). In terms of routine household water disinfection, Aquatabs are currently being used in Haiti, Venezuela, Tanzania, Kenya, and other countries (Medentech, 2006). Another use of Aquatabs is for the disinfection of water tanks, water transporters, wells, boreholes and water pipelines. According to the manufacturer, Aquatabs are preferred over hypochlorite in terms of taste and odor (Medentech, 2006).

The primary function of Aquatabs is to kill pathogenic microorganisms in drinking water, which can cause waterborne diseases like cholera, typhoid, dysentery, diarrhea, etc. They are effective at treating natural waters with various pHs and fecal contamination values (Medentech, 2007).

Aquatabs are non-hazardous for transportation. Additionally, due to the relatively small size of the tablets, they are easily shipped and handled. Aquatabs have a shelf-life of 5 years in strip-packs (typically strips of 10 tablets) and 3 years in unopened tubs.

Aquatabs are also distributed in granular form.

1.4.1 Medentech Background

Aquatabs are manufactured by Medentech Ltd. Medentech is an Irish company that was established in 1984 (Da Vinci, 2006). They are a pharmaceutical manufacture with a certificate of Good Manufacturing Practice (GMP) (Medentech, 2007). The WHO has its own guidelines for GMP pharmaceutical products, which require documentation for each step of product manufacturing (WHO, 2008). This ensures that every unit produced is the same and is of good quality. Most countries will only accept GMP certified products.

Medentech specializes in effervescent (a process by which gas escapes from liquid causing the liquid to "fizz") tablets and granules for healthcare. They have been distributing Aquatabs for relief situations since the mid-1980's. Currently, Medentech manufactures and distributes products to Western and Eastern Europe, Australia, Asia, North America and Latin America.

1.4.2 Aquatab Tablet Weight and Dosing Requirements

Aquatab tablets are available in a variety of sizes to treat specified volumes of water. Furthermore, the volume of treatable water per tablet depends upon the contamination of the water source. For every day use and clear water sources, the dosage should be 2 mg/L of FAC (Medentech, 2006). For emergency situations and dirty/fecally contaminated water sources the dosage should be 4-6 mg/L of FAC. The reason for this increased dosing is that the hypochlorous acid will react with the organic and inorganic materials found in dirty waters. As a result, more needs to be added so that the chlorine can adequately treat the water.

Table 13: Aquatabs and Dosages (Medentech, 2008)

Every Day Use		Emergency Use	
NaDCC Content Per Tablet (mg)	Water Treated Per Tablet (L)	NaDCC Content Per Tablet (mg)	Water Treated Per Tablet (L)
Strip-Packed Product			
3.5	1	8.5	1
17	5	17	2
		33	4-5
67	20	67	8-10
		167	20-25
500	150		
Tablets Packed in Tubs			
1670	500	1670	200
8680	2500	8680	1000-1250

The reason that certain tablets are used only for every day use and others only for emergency use is that some tablets are more relevant for given situations. Typically, the amount of treatable water for dirty/fecally contaminated water sources is half that of clear water sources, when using tablets of the same weight and content. Additionally, the reason that ranges of treatable water are provided in Table 13 is because the amount of treatable water depends on the degree of contamination among dirty water sources. Using 67 mg tablets, only 8 L of heavily contaminated water could be treated, where as 10 L of less contaminated water could be treated with the same tablet.

Therefore, the first step in water treatment with Aquatabs is to select a size/dosage that will adequately treat the water sample. The tablet is then placed in the water sample, it self-dissolves, and in 30 minutes the water is safe to drink. There is no need to stir the water unless the volume exceeds 200 L, in which case the water must be stirred for even distribution. Additionally, waters which exceed turbidity values of 80 NTU should be filtered before treatment (Da Vinci, 2006). (Appendix B includes instructions provided by Medentech regarding the use of 67 mg Aquatabs.)

In keeping with the WHO's Guidelines for Drinking Water Quality (2004), Medentech recommends that the free available chlorine (FAC) levels be greater than 0.5 mg/L 30 minutes after the tablets have been added. Additionally, 24 hours after the tablets have been added, the recommended FAC level should be no less than 0.2 mg/L to ensure that all of the bacteria are killed (CDC, 2008). Medentech also recommends that the FAC level never exceed 5mg/L in the water sample (Medentech, 2006). In contrast, the CDC recommends that 30 minutes after chlorinating there should be no more than a 2.0 mg/L FAC residual (CDC, 2008). These two upper limits of 2 and 5 mg/L FAC residual are used to ensure that there isn't an unpleasant taste or odor in the water

1.4.3 User Acceptability

Aquatabs have been positively accepted according to Medentech supported studies conducted across the world. In Tanzania, 70% (42 of 60) of people preferred Aquatabs to hypochlorite (Medentech, 2006a). Likewise, in a 350 person study in Brazil, the same percentage of people preferred Aquatabs to hypochlorite (Medentecha, 2006). Also, during a four-week study in Bangladesh, 78% of 380 people favored the use of Aquatabs. A 200-person study in rural Honduras found that Aquatabs were the first choice for water purification products. Reasons for these positive acceptability rates include ease of use, storage and minimal chlorine taste.

1.4.4 Performance

Numerous studies around the world have been conducted on the performance of Aquatabs. In 1993, Aquatabs reduced TC counts among water samples taken in Kenya from levels as high 2,400 CFU/100mL to 0 CFU/100mL in just 30 minutes. Likewise, in tests done in South Africa, the TC count was reduced from 1,400 CFU/100mL to 0 CFU/100mL in a similar time frame. Similar studies have proven Aquatabs to drastically reduce TC counts in Zimbabwe (1998), Tanzania (2005), France, Brazil, Honduras, Spain, the Dominican Republic, Vietnam, Portugal, El Salvador, India, Swaziland, and Pakistan (Medentech, 2006).

During a four-week pilot study in Bangladesh mentioned in the above section, mothers were given 67 mg tablets for water treating 20 L of water per tablet (Molla, 2006). Untreated waters had TC counts in excess of 103 Most Probable Number (MPN of coliforms)/100 mL. After treatment, the average microbial concentration in water samples was 1.4 MPN/100mL (Medentech, 2007). Likewise, the FAC tested was between 0.2-2.8mg/L. In terms of health effects, prior to the pilot study 100% of children under the age of five had diarrhea. After the study, 65.7% of those same children were free from diarrhea. Furthermore, there was an 85.7% reduction in cases of severe diarrhea (Molla, 2006).

1.4.5 Extent of Use Worldwide

Hundreds of millions of Aquatabs have been supplied worldwide to pharmacies, drug stores, emergency relief efforts, travel markets, and defense forces (Medentech, 2006). Currently, Aquatabs are available in 40 countries (O'Callaghan).

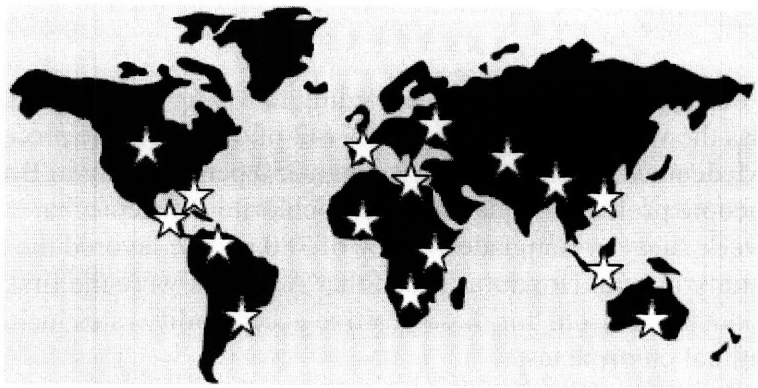


Figure 11: Geographical locations where Aquatabs are used (Medentech, 2006).

Some of the countries with which Medentech is currently (or is on course to) working with for long-term, household water treatment programs include Algeria, Haiti, Indonesia, Kenya, Philippines, Sudan, Swaziland, Tanzania, Uganda, Venezuela, and Ghana (Medentech, 2006a).

1.4.6 Extent of Use in Ghana

Currently there are no Aquatabs in use in Ghana. In preparation for implementing this technology, Medentech funded a Center for Disease Control (CDC) pilot study in 2006 on the use of Aquatabs in Bipelar, a middle-class community in Northern Region, Ghana (Blanton, 2006). It is important to note that Bipelar is a community with access to piped water supply. However, many rural communities in Northern Region, Ghana rely solely upon dam water as their drinking water source. The high turbidity in these dam waters makes chlorination by itself—without other treatment—unstable, which is likely why a community with a piped water supply was selected.

Blanton, the principal investigator for the CDC, surveyed 240 households which included 3,240 household members in Biplar. She taught these households how to use the Aquatabs, provided a three month supply, and then returned 22 times to follow-up and to do water testing. At the end of her survey, 98% of the households were still using the water treatment tablets. Additionally, 75% of the water samples taken consistently showed a FAC residual greater than 0.1mg/L. In terms of EC, Blanton compared households that she provided with Aquatabs with a control group using a placebo. Among the households with Aquatabs, the percentage of samples with no indication of EC present increased from 4.2%-83%-92% from her baseline visit to her midterm visit to her final visit, respectively. Likewise, among the control households the samples with no indication of EC present varied from 12.5%-9.1%-50% from her baseline visit to her midterm visit to her final visit, respectively.

After a tragic flood devastated Northern Ghana in September, 2007 leaving thousands homeless and without water, Medentech shipped 10 million Aquatabs to support the flood victims. After long delays, these tablets were cleared through customs in December, 2007 and are now ready for distribution.

1.5 Objective of Research

Individually, neither the *Kosim* filter nor Aquatabs are capable of adequately treating the extremely turbid dam or river water that many people in Northern Region, Ghana drink. Previous research indicates that while the *Kosim* filter is effective at significantly reducing the amount of suspended particulates (turbidity) and greater than 99% of the TC and EC, it does not remove 100% of the TC and EC present in the water sources. Similarly, while Aquatabs are effective at eliminating bacterial indicators in relatively clean water sources, the highly turbid water in Northern Region, Ghana poses significant challenges to chlorination. Therefore, by first filtering turbid water through the *Kosim* filter, and then chlorinating the filtered water with Aquatabs, it is thought that a superior treatment will be obtained than could be had with either technology alone.

This thesis explores the effectiveness of this combined technology for lower and lower-middle class communities in Northern Region, Ghana, whose primary drinking water supplies are contaminated surface waters. It also surveys user acceptability (i.e. "use" and "sustained use") of this complementary system.

2.0 Research Methodology

2.1 Goals of Research, Comments and Logistics

The goal of this research is to determine whether a combined water treatment technology consisting of a *Kosim* filter and Aquatabs is an effective and practical household water treatment system for Northern Region, Ghana. In order to do this, one must not only determine the technical efficacy but also interact with the people and communities that are potential targets for such a system. Before beginning research, a number of factors had to be considered.

Household water in the Northern Region of Ghana is typically collected from both improved and unimproved sources, including dams, river/streams, boreholes, protected or unprotected dug wells, rainwater, and/or piped water supply. In urban centers and towns, it is also often purchased in plastic bags (sachet water). Ideally, everyone would have access to improved water supply systems such as boreholes, protected wells, or piped water supply. However, the reality is that many communities either can't afford such improved water supply systems, or they are not available. Therefore, the target of this research is communities that rely primarily on dams and other unimproved water sources as their drinking water supply. These communities are typically rural or peri-urban, with households of traditional construction (as described previously).

Another factor this research considered was the ability of users to sustain the use of the system (i.e. consumer acceptance and be willingness to pay for Aquatabs once they were no longer provided for free beyond the period of the author's pilot study). The sustainability of this system is just as or even more important than the technical performance. And while the *Kosim* filter is a one-time purchase, Aquatabs require continued purchasing for the duration of use. Because of this, it is important to gain insight regarding the user acceptance in communities of varying economic means. This diversity of information will allow for more complete conclusions to be drawn about the potential sustainability of this dual system.

Furthermore, aside from the pilot study conducted by the CDC described previously, Aquatabs are a foreign product imported into this region, which presents a number of challenges. For one, while Ghanians are accustomed to the introduction of new products and assistance from foreign donors, they may be most comfortable using products that are similar to ones they already use. For example, the *Kosim* filter is a very simple technology and one that is similar to the clay storage vessels used in rural households, therefore it is highly compatible with indigenous practics. In each rural household, composed of roughly 12-14 people (Green, 2008, Blanton, 2007, Peletz, 2006), there are typically 2-5 large, circular, clay storage vessels, which hold water brought from the dams. It is hypothesized that this familiarity with ceramic vessels results in Ghanians feeling more comfortable using a similar product like the *Kosim* filters. On the other hand, Aquatabs are small, chlorine tablets, for which there is no comparable product in rural Ghanian communities (except, perhaps, medicine). As a result, it is thought that people from these communities may not as readily accept or properly use Aquatabs because of cultural conservatism or lack of proper training and oversight. Therefore, appropriate education—with respect to user acceptance and proper use—was a consideration in this pilot study.

Because the ability to conduct this research was dependent upon user acceptance, it was decided that households already using *Kosim* filters would be targeted for this study. That way, the community members would only need to be educated on one new product, as opposed to two new products. Further, it was decided that the Aquatabs would be distributed for free for the duration of the study. This was done to ensure participation from all of the community members.

2.2. Research Plan

In order to determine the effectiveness and user acceptability of this combined system, it was decided that roughly 70 households would be targeted for a pilot study. This number was optimistically chosen based upon the maximum number of households previous MIT MEng students were able to visit in a three week period (Peletz and Johnson visited 50 and 42 households in 2006 and 2007, respectively).

Furthermore, while English is the official language of Ghana, local dialects are the languages of rural communities. In these communities, the women are in charge of the household water collection and management. In Northern Region, Ghana, only 13% of women are literate, and most speak little-to-no English (GSS, 2003). As a result, translators were needed to communicate with the community members. The primary aid for translation and education was Napps, a 23 year old Ghanian student. Tuu-Naa was also hired to assist with translation and education. Finally, the village volunteers of the two selected communities, Chairman and Zach, assisted when available.

During household introductions, participants were informed about the purpose of the study and were given the option to declare participation. Once they agreed to participate, a baseline introduction was conducted with the households to ensure that they were appropriately using functional filters. The "filtered-only" water was sampled for turbidity, EC, and TC and the households were instructed in the use of Aquatabs, given a one week supply, and told that a return visit would occur in one week. During the return visit, any questions were answered about the combined system, and the filtered and chlorine disinfected water was tested. This process provided insight into the user acceptability and performance of the combined system.

2.2.1 Community Selection Strategy

As previously discussed, communities were not randomly selected. Instead, three screening criteria were used to determine which community(ies) would be the focus of this study. Only communities that already owned a *Kosim* filter and that use dams as their primary drinking water source were considered. Another consideration for selecting communities was the proximity of the communities to the author's lodging site, given that transportation options were limited. While in Tamale, a house was rented by the MIT team in the area called SSNIT, which is roughly 2 miles northeast of downtown Tamale.

The original plan was to target 70 households for distribution. And in order to gather information from various economic backgrounds, it was decided that one lower-class community would be chosen and one middle-class community. Therefore, it was also a priority to ensure that communities of an appropriate size were selected—roughly 35 households per community—so that every household possessing a *Kosim* filter was given Aquatabs. This was important so that people did not get upset about unfair distribution. It was also important because if everyone in the community has the combined system, there is a greater likelihood that they will use it because it was anticipated that they might talk with their neighbors and potentially encourage each other to use the new product.

Weighing all of these different considerations, Kalariga was selected as the lower-class community. This community is located roughly 2 miles southeast of downtown Tamale. In a previous research study, Brandies University Master student Alioure Dia distributed 24 *Kosim* filters to 23 households (2 for the village volunteer) for free[1]. This distribution occurred in January, 2007 (Dia, 2008). The households in this community are composed of small, circular homes of mud-brick construction, with thatch roofs, and dirt floors. In a typical household, there are six circular building units. These units also form a circle, with mud-brick walls connecting the various units. There is a door to the household between two of the units. In the middle of this circle of units there are fire pits, where the cooking and cleaning is done. The main water source for the community of Kalariga is a dam located roughly 1/3-1 mile south of the community.

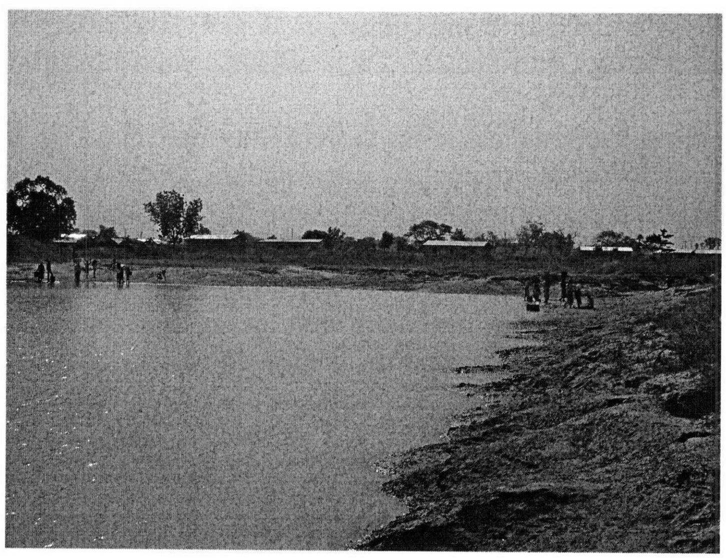


Figure 12: Kalariga Dam.

[1] Dia, a Muslim from Senegal, disagreed on philosophical and religious grounds with the PHW strategy of selling filters to the poor. His study design therefore entailed free distribution of 25 filters—with close follow-up over a 6 month period.

At some point into the dry season, the Kalariga Dam dries out completely. At that time, people must travel roughly 1 mile to the Ghanasco Dam for water collection.

The other community selected was Kakpagyili, a lower middle-class community located roughly 2 miles due south of downtown. There are 35 *Kosim* filters in the community of Kakpagyili, which were sold to the community 3 months prior to the visit. The households in this community are a mix of traditional construction (similar to Kalariga), and modern construction. Modern construction is typically done with concrete walls, concrete floors, and tin or tile roofs. The primary water source for Kakpagyili is one of two dams. One is located ½ mile north of the community (KakDam1), and the other is located ½ mile south of the community (KakDam2). The community members generally travel to whichever dam is closer.

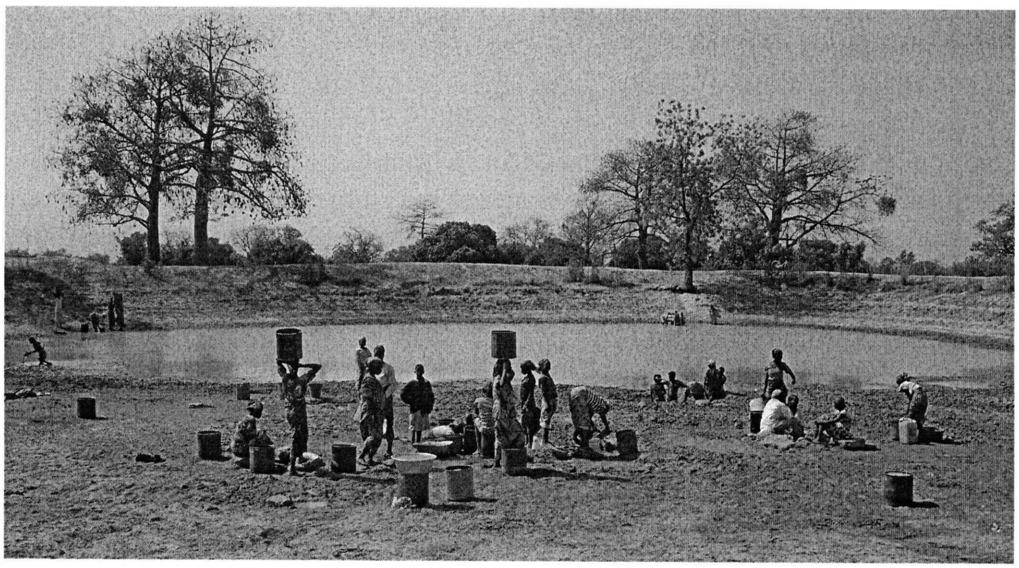


Figure 13: Kakpagyili Dam 1 (KakDam1).

There is also a piped water supply near Kakpagyili. However, it is only available to certain households, and it generally is only available for the early portion of the dry season because the water source dries up (Okioga, 2007). Afterwards, everyone has to use the dam water.

This community was chosen because of its proximity to Bipelar. As mentioned previously, Bipelar is the community where the CDC pilot study was conducted on Aquatabs. The reason Bipelar was not selected for this study is that they have access to piped water supply. Therefore, it was decided that a community near Bipelar would be appropriate in the hope that some people from Kakpagyili would have heard about Aquatabs from their neighbors in Bipelar.

Water quality data has been collected for some of the dams servicing these two communities by Johnson, Foran, and Yazdani in 2007.

Table 14: Water Qaulity of Dams Servicing Kalariga and Kakpagyili (Johnson, 2007, Foran, 2007, Yazdani, 2007)

Dam	Source	Turbidity (NTU/TU)	TC (CFU/100mL)	EC (CFU/100mL)
Kalariga	Johnson, 2007	159.2	43,000	785
Kalariga	Foran, 2007	>2000	13,475	754
Ghanasco	Foran, 2007	1,600	6,621	169
Ghanasco	Yazdani, 2007	817	57,825	25
KakDam1	Foran, 2007	38	21,667	100

There has been no previous water quality testing on KakDam2. The turbidity, TC, and EC values presented in Table 14 are similar to the pre-treatment values in Table 8, and greatly exceed drinking water guidelines.

2.2.2 Participant Selection Strategy

The communities were chosen such that every household in possession of a *Kosim* filter in Kalariga and Kakpagyili was visited as part of the study, resulting in a census from the two communities. Therefore, 59 total participants were approached and agreed to participate in the study.

2.2.3 Development of Dosing Protocol

Prior to distribution, it was important to develop a consistent dosing protocol for the combined system. 67 mg tablets were the tablets available for this research study. Medentech advises that a 67 mg tablet be added to 20 L of "clear water" or 8-10 L of "dirty water". Four different dosing strategies were considered:

1. Dose directly into ceramic pot, before filtration
2a. Add Aquatab to storage receptacle by drilling a hole in side
2b. Add Aquatab to storage receptacle by lifting ceramic pot
3. Provision of 20 L jerry cans specifically for dosing

Option #1 was to dose the water before filtration. If the Aquatabs were added prior to filtering, then the dam water would certainly be considered "dirty", and an 8-10 L volume of water would be appropriate. The volume of the *Kosim* filter is 9 L, which is within this range. Therefore, for this dosing strategy, the households would fill their ceramic pots and immediately add one Aquatab to the water. The primary advantage associated with this option is that it is easy for the households because it doesn't require any lifting or further preventative sanitation measures. However, this method was not chosen for two reasons. For one, once the water is added to the ceramic pot, filtration begins immediately. Medentech suggests that households wait 30 minutes for the Aquatab to fully dissolve and react with the water sample. Therefore, if the Aquatab was added directly into the ceramic filter, then some of the water would filter through the sides in the first 30 minutes, which wouldn't interact with the chlorine. Another complication is that the turbidity in the water samples would act as a shield for the bacteria. When

Medentech refers to dirty/fecally contaminated water, they are likely not referring to water with turbidity 100-2,000 TU. Therefore, this option was discarded.

Option #2 is to add the Aquatabs directly into the storage receptacles provided with the *Kosim* filters. As currently manufactured, the filtered water is completely covered by the lid on the storage unit and the ceramic filter. Therefore, two different methods of dosing were brainstormed. One option would be to drill a hole large enough for one 67 mg Aquatab in the side of the storage receptacle. This hole would be sealed with Duct Tape or some other adhesive tape, which would prevent contamination of the filtered water. Another method would be to lift the ceramic filter out of the storage receptacle and add an Aquatab to the filtered water. Filter owners are already accustomed to frequently lifting the ceramic filter out of its container in order to clean it, but are instructed not to lift the ceramic element when it contains water—due to concerns with breaking the lip of the pot.

These methods are advantageous because they utilize the covered storage receptacles and so there is no need for the provision of another safe storage container. These methods are also aided by the fact that the storage receptacles have volume measurements (marked in 5 L increments) that are already along the side of the plastic receptacles. Because the dosing protocol calls for one 67mg Aquatab tablet to be added to 20 L of "clear" water, with this method one would filter water until it reached the 20 L mark, add the Aquatab, wait 30 minutes, and then the water would be ready for drinking.

Both of these strategies are appealing because of their simplicity. However, there are a number of disadvantages. For one, both options allow for the possibility of recontamination. With the drilled hole, airborne particles and microbes can enter the storage receptacle unless the hole is sealed at all times. Because there is no simple way to prevent this, one is taking a risk in assuming that contamination won't occur. The same problem is associated with lifting the ceramic pot out of the storage receptacle to dose. While dosing is taking place, the uncovered water may become recontaminated by airborne particles. A further complication with this dosing strategy is that there is a greater likelihood that breakages will occur. Any time that the ceramic filter is handled, there is a possibility for accidents to happen. Therefore, by requiring the households to handle their filters every time that they dose their water, one is providing more chances for breakages.

These dosing strategies are also rather inefficient due to the relatively slow flow rate through the *Kosim* filter. As described previously, water flows through new *Kosim* filters at a rate of 1-2.5 L/hr (a value which decreases with use as the pores become clogged between cleanings). In order to comply with the dosing values prescribed by Medentech, if the Aquatabs were added directly into the storage receptacle, then no additional water could be filtered through the filter until all of the chlorinated water was consumed. This means that 20 L of water would be available after dosing. However, all of this water would need to be consumed before more water could be filtered through the *Kosim* filter. As a result, there would be no drinking water available from the time the chlorinated water was consumed until 20 L of new water was filtered through the *Kosim* filter. And with such limited flow rates through the filter, it was decided that using the *Kosim* filter storage receptacle for dosing was impractical.

Therefore, Option #3 was decided upon for this research study. This option is to provide households with 20 L containers specifically for dosing. Locally made, readily available storage receptacles of that volume were sought. The most practical storage container found in Northern Region, Ghana was 20 L plastic containers called jerry cans. In Ghana, jerry cans of various sizes are common and are typically used to store palm oil. They are easily purchased in most market places for GHC 1 GHC (US $1). With the provision of this additional storage container, the households could continually filter water through their *Kosim* filter even after the jerry can was filled and dosed. To ensure participation, it was decided that the jerry cans would be provided free of charge for this study, along with the Aquatabs.

2.2.4 The Survey Instruments

In order to obtain dependable user acceptability results from the study participants, two surveys were created for personal interviews, which is often the most effective way of enlisting cooperation in research projects (Fowler, 1993). This strategy allows for probing inadequate answers and multimethod data collection (e.g. observations). The development of these surveys also increases the dependency of the results, because all questions are asked the same to each participant.

The first survey was developed for use during the initial visit to the households already using the *Kosim* filter. Its purpose was to inquire about the functionality and effectiveness of their *Kosim* filter. This survey was conducted to ensure that the households were using their filters properly—and that none of the filters were broken—before the study began. The survey was also developed to gauge the satisfaction level of the sole use of the filter. At the conclusion of this survey, households were instructed in the use of the combined *Kosim* filter and Aquatabs system and were given a jerry can and an initial supply of Aquatabs.

The second survey was developed for the follow-up visit, after the households had already had an opportunity to use the Aquatabs. The purpose of this survey was to gauge the satisfaction level of the complementary use of the *Kosim* filter and Aquatabs. It was also developed to determine how much the community members would be willing to pay for the Aquatabs, if they were for sale in the market.

Both surveys are included in Appendices C and D.

2.2.4.1 Baseline Survey

Concurrent to the author's research, another team member, MIT student Kate Clopeck, was focusing her Masters level research solely on the subject of use/sustained use of the *Kosim* filter disseminated by PHW from 2005 to present. Therefore, many questions in the author's baseline survey are common to Clopeck's survey. The difference is that the observational question, "How much water is in the receptacle?" was added.

The initial portion of the survey was written to inform the households about the research that was being done, to obtain participant's informed consent, and to obtain information about the household for identification purposes. Each household was informed that a research study was being conducted on the combined use of the *Kosim* filter and Aquatabs, that their participation in the study was voluntary, and that all information they provided would be kept confidential. If the household consented to participating in the survey, then questions were asked regarding the name, age, and household status of the respondent. This information was important to ensure that the appropriate households could be revisited in follow-up surveys.

The first set of questions pertains to the actual use and history of the *Kosim* filter. As part of these questions, the survey respondents are asked to show the *Kosim* filter and the water that they use to fill the *Kosim* filter. They are also asked if their filter is working properly. These questions are asked to establish that the household members are using a functional filter. Other relevant questions in this section include inquiring how long they have had their filter, as well as how many times per week they fill their filter.

Another important consideration before distributing Aquatabs was to confirm that the households are properly maintaining their filters. In the next series of questions, the survey respondents were asked about the maintenance of their filters. Initially, they are asked to act out the cleaning of their filters. They are also asked when was the last time they cleaned their filter, as well as how many times they clean their filter per week. These questions are important as households using dam water were targeted in this study. Because households are using dam water, the turbidity values are extremely high in the water source, which means that a large amount of suspended particulates will be filtered out during filtration. If these suspended particulates are not scrubbed off of the ceramic filter, then they will impede the flow of water through filter.

The last series of questions was developed to gauge how satisfied the community members were with their *Kosim* filter. Questions were asked regarding the taste of the filtered water, if the filter was easy to use, whether it had ever broken, etc. One question on the survey was about whether the community members treated their water before they had the *Kosim* filter. Every household that was surveyed was previously supplied with a Guinea Worm Cloth Filter as part of the free distribution by the Guinea Worm Eradication Campaign. Because these filters were distributed as "filters", all of the survey respondents indicated that they did, in fact, previously filter their water. The last question of the baseline survey was about when the last time someone from the household had had diarrhea. All of this information is important because if the community members are already satisfied with the current level of treatment using the cloth filter and/or the *Kosim* filter, then they will be less inclined to use the Aquatabs in addition to the *Kosim* filter.

2.2.4.2 Follow-up Survey

The second survey was developed for the return visit to the households. After the first survey was conducted, the community members were given a 20 L jerry can and a one-week supply of Aquatabs for free, and were instructed how to the use them. They were also informed that there would be a return visit in one week to answer questions and test their water. The format of the second survey was similar to the baseline survey, including household information, use, perception, and cost-related questions.

The same household information questions as asked in the baseline survey were asked in the follow-up survey. These questions were asked to properly identify the households, and thus allow for the comparison between the two surveys and the two sets of water quality results

The first questions from the follow-up survey were developed to inquire about the use of the Aquatabs in combination with the *Kosim* filter. The respondents were asked if they used the Aquatabs, and if so, how many Aquatabs they had used during the previous week.

The next set of questions concerned the household perception of the Aquatabs. The respondents were asked if the Aquatabs improved the taste of the water. They were also asked questions about whether the Aquatabs were easy to use, if they had experienced any problems using the Aquatabs, and if they would recommend Aquatabs to others. The households were then asked if anyone in the household had had diarrhea in the previous week. This series of questions was asked to evaluate the household's overall satisfaction with the product.

The last question was related to the cost of the Aquatabs. This question was important to include because if the community members were unwilling to purchase the Aquatabs after the conclusion of the study, then it wouldn't matter how effective the Aquatabs were at treating the water. The manufacturer of Aquatabs currently charges US $0.03 for 1 Aquatab. This equates to US $3 for 100 Aquatabs, which is roughly the same as GHC 3 for 100 Aquatabs. Therefore, the households were asked if they would spend GHC 3 for 100 Aquatabs. If they said no, then they were asked what they thought a fair price was for 100 Aquatabs.

2.2.5 Survey Implementation and Logistics

In order to visit traditional (rural) households in Northern Region, Ghana, one must first visit the village chief. The chief is in charge of the community, and lives in the chief's palace. The chief's palace is similar to other households, although sometimes they are larger and more luxurious. When visiting the village chief, one explains what it is he/she will be doing in the community. The chief then either grants his permission, or prohibits one from working in the community. Typically, the village chiefs are pleased that people are trying to help, and are welcoming.

After visiting the village chief, one must then contact the village volunteer (introduced earlier). The village volunteer in Kalariga is called Chairman or Youth Chief, and the village volunteer in Kakpagyili is named Zach. The village volunteers were critical to this research effort as they knew which households had the filters. Also, even after meeting the village chief, it is not polite to enter households unless you are accompanied by someone from the community. So the village volunteers were also important for making household introductions.

For the initial visit, every household that had a filter was entered with the village volunteer, the guide/translator Napps, and the author. Then the man/woman who was in charge of maintaining the *Kosim* filter was surveyed. Questions were asked in English, and then translated into Dagbani (the local dialect) by the village volunteer or Napps. Responses were given in Dagbani, and translated into English for the author. For the initial visit, the baseline survey was conducted and a filtered only water sample was taken. Afterwards, the village volunteer or Napps educated the person in charge of the *Kosim* filter about Aquatabs, provided a jerry can and a one week supply of Aquatabs for free, and informed them that there would be a return visit in one week to answer questions and test the water.

In one week, the same households were revisited. It was no longer necessary to be accompanied by the village volunteer as introductions had already been made the previous week. During the return visit, the follow-up survey was conducted in the same fashion as the baseline survey. At the conclusion of the survey, a water sample was taken from the filtered and chlorine disinfected water. The survey respondents were then given an additional 2-3 month supply (depending on the frequency of use) of Aquatabs, and were informed that someone would be back in one month to further answer questions and test their water.

2.2.6 Strengths and Limitation of Methodology

One of the primary limitations of this research methodology is that it does not allow for a direct comparison between filtered only water and filtered and chlorine disinfected water, and thus does not allow for a household-by-household assessment concerning the effectiveness of Aquatabs. This is because the samples are taken at different times (the filtered only water during the baseline visit and the filtered and chlorine disinfected water during the return visit). This would not be a concern if the water sources were consistently of the same quality. However, this is not the case in Northern Region, Ghana. Dugout water quality varies depending on whether the water has recently been stirred (which increases turbidity), and due to regional and seasonal variation in microbial concentration within water sources. This is evident in the varied water quality results gathered by Johnson and Foran on similar dams, as discussed earlier. If water of different quality is being treated, then it is difficult to make direct comparisons between the filtered-only samples and the filtered + chlorine disinfected samples.

However, even though direct household-by-household comparisons are difficult to assess with this methodology, with a large number of households, general water quality trends can still be determined. Furthermore, by allowing participants a duration of time to use the combined system, one can obtain user perception results. The longer one waits between baseline and follow-up visits; the longer individual households are able to use the combined treatment system. As a result, households will be better able to answer questions regarding the system and understand its strengths and limitations. On the other hand, with more time passing before follow-up, it is more likely that the quality of water sources will vary due to seasonal variations in the quality of the dugouts and to the amount of time that water is allowed to settle in the storage vessels. Therefore, it was decided for this study to wait one week between baseline and follow-up visits and to follow-up again 6 months later. This gave households an appropriate amount of time to use the combined system, without being so long that the quality of the water sources varied dramatically.

2.3 Water Quality Testing Methodology

The four water quality parameters of most importance for this research study were turbidity, TC, EC, and FAC residual. The turbidity, TC, and EC were tested during the initial baseline visit and the follow-up visit. The FAC residual was tested only during the follow-up visit, after Aquatabs had been applied.

2.3.1 Sampling Methods

Turbidity and FAC residual results were both tested for in the households. Turbidity was tested with a turbidity tube, and the FAC residual was tested with a Hach Digital Titrator. The TC and EC cannot be tested for in the household, so samples were collected in Whirl-Pak® sampling bags. Whirl-Pak® bags are sterile, transparent, plastic, single-use bags used for sampling liquids.

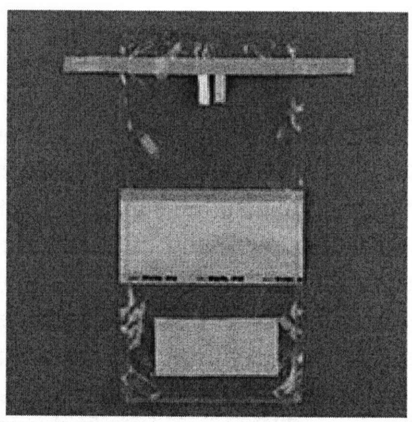


Figure 12: Example of Whirl-Pak® sampling bag used to collect water samples (LabShop).

There is a perforation at the top of the bags, which allows for the top of the bag to be easily removed. Directly below the perforation, there is a double-wire framing, which allows for the bag to be easily held open. Once liquid has been added to the bag, the wire is whirled around the top of the plastic to seal the bag. Additionally, there is a white strip around the center of the bag so that bags can be marked.

In order to prevent the bacteria in the water sample from further growth, the sample must be kept cool. To ensure this, a cooler was carried while taking samples in the field. The samples were taken back to the house at SSNIT within a period that was always less than 6 hours, where a sterile field laboratory was set-up. Once in the lab, 3M™ Petrifilm™ microbial testing equipment was used to test and analyze the samples for TC and EC.

2.3.2 Field Laboratory

A laboratory was set-up at the lodging site, which was completely sterilized with alcohol.

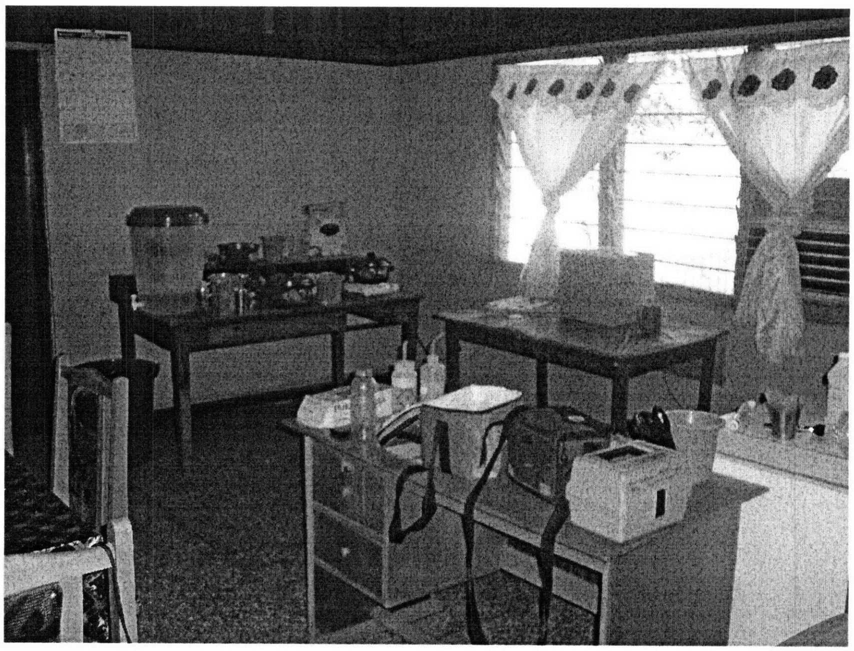


Figure 14: Field laboratory at lodging site.

A *Kosim* filter was in the lab to filter the vended tanker truck water, available at the house. After filtering, the tanker truck water was boiled with an electric stove to sterilize pipette tips. The tips were then placed in a sterilized container, ready for use. Once sterilization was complete, the boiled water was brought to room temperature, and was then used for diluting water samples. While using the same water for sterilization and dilutions is not ideal, water was scarce at the house. The lab also had a Millipore Portable Single Chamber Incubator for bacteria samples, and plenty of counter space—with appropriate lighting—for microbial testing.

2.3.3 Turbidity Tube

Turbidity was tested during the baseline and follow-up visits to the households. It was measured to ensure that the *Kosim* filters were working effectively. The instrument used to measure this value was a turbidity tube from DelAgua Ltd.

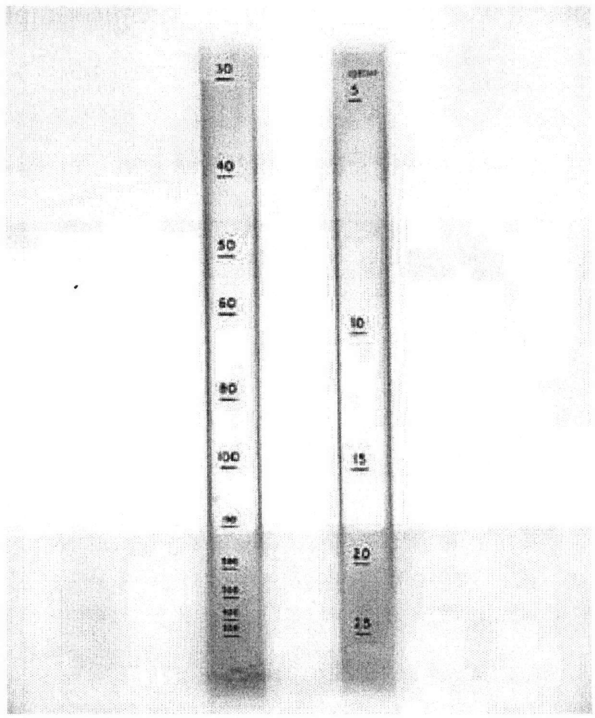


Figure 15: Turbidity tube (DelAgua).

This tube comes in two pieces so that it can be easily transported. To perform this test, the two parts are pushed together to form one elongated tube. There is a circular "bulls-eye" target at the bottom of the tube. When one is ready to take the turbidity reading, the water sample is slowly poured into the turbidity tube, until the target is no longer discernable to the naked eye. At this point, the water level in the turbidity tube is read from the outside, and the value is recorded. After use, the turbidity tube must be cleaned with pure water before using again.

The limit of detection with a turbidity tube is <5 TU. Therefore, for averaging turbidity values and for presentation in graphs, measurements of <5 TU were treated as 2.5 TU, which is the middle of the range below 5. This was done because with enough samples the average would likely be near this value.

2.3.4 Digital Titration

FAC residual was tested during the follow-up visit to the households. As described previously, according to the manufacturer's specifications, the minimum FAC residual should be 0.5 mg/L 30 minutes after an Aquatab tablet has been added to 20L of water. Additionally, there should be a minimum FAC of 0.2 mg/L 24 hours after application, and there should never be a FAC in excess of 5 mg/L. With these limits in mind, it was important to test the FAC during the return visit to the households. As part of the survey, the respondents were asked when the last Aquatab was added to the water sample, and the FAC was tested with a Hach Digital Titrator, as shown in Figure 16 and Figure 17.

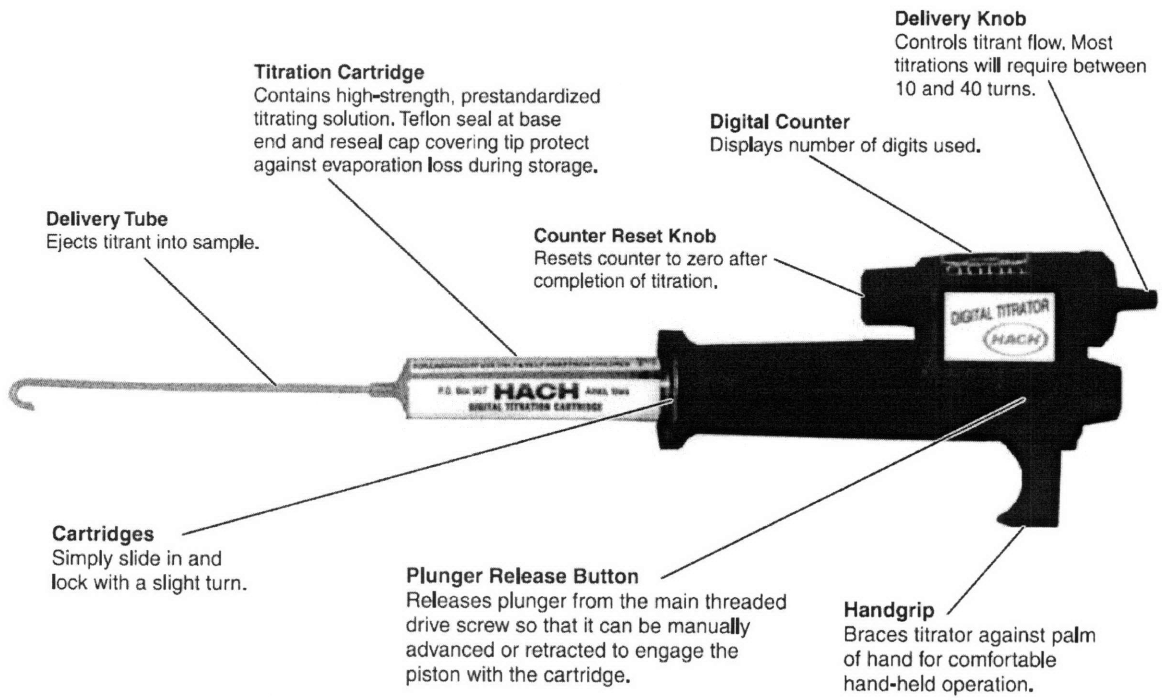


Figure 16: Hach Digital Titrator components (Hach, 2006).

Digital Titrator Components:
-13mL Titration Cartridge
-Delivery Tube
-Hach Digital Titrator
-50mL Beaker
-Hach Free Chlorine Powder Pillow

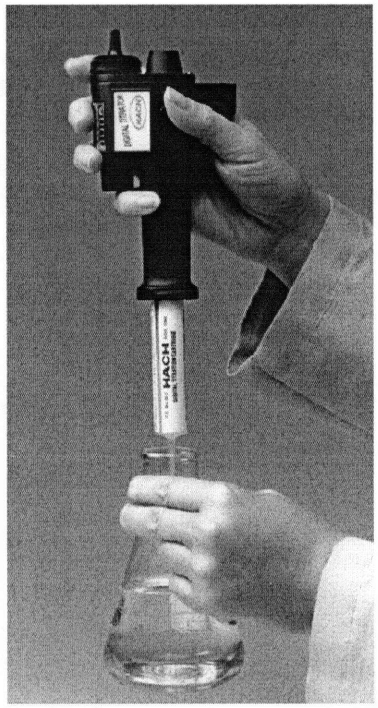


Figure 17: Hach Digital Titrator assembly (Hach, 2006).

The procedure below is adapted from Hach's *Digital Titrator: Model 16900* instructions. (Instruction sheet included in Appendix E).

1. Slide the titration cartridge into the receptacle and lock in position with a slight turn.

2. Remove the polyethylene cap from the titration cartridge and insert a clean delivery tube into the end of the cartridge.

3. Advance the plunger release button on the Digital Titrator to engage the piston with the cartridge. Turn the delivery knob until air is expelled and several drops of solution flow from the tip. Then use the counter reset knob to turn the digital counter back to zero and wipe the tip.

4. Measure 25 mL of the water sample and add to the beaker.

5. Add the Free Chlorine Powder Pillow to the water sample and swirl the beaker. Wait for 3 minutes. If there is a FAC level, the water sample will turn pink.

6. Immerse the delivery tube tip in the solution and swirl the flask while titrating. Titrate by turning the delivery knob. Keep turning the knob and swirling the sample until the water sample has turned clear. Record the number of digits that appear in the digital counter window.

7. Calculate the concentration of the sample by multiplying the value recorded in Step 6 by 0.01 to obtain the FAC level in mg/L. (According to Hach, a 0.01 digital multiplier is appropriate for determining the free or total chlorine of a sample within 0 to 3 mg/L Cl_2.)

8. After completion, press the plunger release button and manually retract the plunger into the body of the titrator. Remove the cartridge. Remove the delivery tube and reseal the cartridge with the polyethylene cap.

9. Clean the delivery tube immediately after use by forcing clear water—then air—into the tube opening.

10. Discard the water sample, and rinse the beaker with clean water

This process was performed in the field.

2.3.5 3M Petrifilm™ Testing E. Coli/Coliform Plate Count

As described previously, indicator organisms are typically used in bacteria testing to test for the likelihood of bacterial pathogens. In this thesis, TC and EC were used as indicator organisms and 3M Petrifilm™ *E Coli*/Coliform Plate Count was used as the test method.

3M Petrifilm™ Materials:
-3M Petrifilm™ *E. Coli*/Coliform Plate Count
-Plastic Spreader
-Automatic Pipette (Oxford)
-Pipette Tips
-Tongs
-Millipore Portable Incubator, XX 63 200 00

The chilled water samples were returned to the lab in Whirl-Pak® sampling bags after the completion of each day's fieldwork.

The procedure below is adapted from *3M Petrifilm™ E.Coli/Coliform Count Plate: Instruction Manual (2000).*

1. (Keep packages of 3M Petrifilm™ refrigerated prior to use.) Place petrifilm plate on a level, sterile surface, with the gridded side down. Lift the top film.

2. Use Automatic Pipette with a sterile tip to place 1 mL of well-mixed sample onto the center of the bottom film. For highly contaminated waters, perform appropriate dilutions (typically 1:10 dilutions were performed in Ghana, unless water source was extremely contaminated, in which case dilutions of 1:100).

3. Roll the top film slowly onto the bottom film. Be careful not to create air bubbles.

4. With the flat side down, place the spreader on the top film over the inoculum.

5. Gently apply pressure on the spreader to distribute water sample over the entire circular area of the 3M Petrifilm™ and to activate the gel.

6. Lift the spreader. Wait at least 1 minute for the gel to solidify

7. Incubate plates in Millipore Portable Field Incubator at 35° C for 24 hours (+/-2 hrs). Plates should be placed in the incubator with the gridded-side down in stacks of up to 20 plates.

8. After 24 hours, remove plates from incubator and count the colonies. Blue colonies with entrapped gas in association indicate the presence of EC, while the sum of the red and blue colonies with entrapped gas in association indicates the presence of TC. Colonies without entrapped gas are not counted.

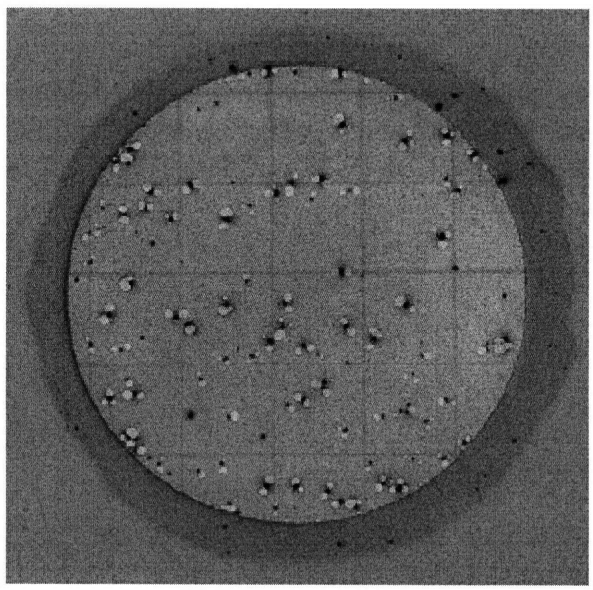


Figure 18: 3M Petrifilm™ test results. Red colonies with entrapped gas in association indicate EC, the sum of blue and red colonies with entrapped gas in association indicate TC (3M Petrifilm™, 2001).

For 1 ml samples the limit of detection using this method is <100 CFU/100mL. Therefore, when there is no TC or EC present, the value will be recorded as <100 CFU/100mL, however, for averaging test results and for data presentation in graphs, plates that had no TC or EC present will be treated as 50 CFU/100mL. This value is in the middle of the <100 CFU/100mL range, and thus—with enough samples—represents the expected average value for these measurements (Sung, 2008).

3.0 Survey, Water Quality, and Flow Rate Results

Survey responses were recorded for each of the 59 households visited. In the following chapter, results are presented in a series of tables and charts. Data is categorized by the type of response. For example, yes/no questions are compiled into one chart, qualitative questions about water sources another chart, etc.

The turbidity, microbial, and FAC test results are also included in this chapter. Each individual household's water quality results are presented in charts and graphs. A complete table of the water quality results is appended in Appendix G.

Finally, the last portion of this chapter includes flow rate test results performed on seven ceramic filters with varying water sources. This information is presented in a number of plots.

3.1 Baseline Survey Results

The baseline survey includes 16 questions pertaining to use, maintenance, and perception. Many of the questions on the survey are not verbalized questions, but rather observations made by the surveyor. For example, Question 1a is, "Is the ceramic filter installed in the unit?" For this type of question, the response was recorded based on observation, without consulting the household.

3.1.1 Filter Use Survey Results

The first 7 questions on the baseline survey pertain to filter use. Many of these questions were answered with yes/no responses, which were then compiled numerically (and by percentage) into one table.

Table 15: Yes/No Responses for Baseline Survey Filter Use

#	Question	Kalariga		Kakpagyili		Total	
		Yes	No	Yes	No	Yes	No
1 a	Is the ceramic filter installed in the unit?	24/24 100%	0/24 0%	35/35 100%	0/35 0%	59/59 100%	0/59 0%
1 b	Is the filter covered with a lid?	24/24 100%	0/24 0%	35/35 100%	0/35 0%	59/59 100%	0/59 0%
3	Is your filter working?	24/24 100%	0/24 0%	35/35 100%	0/35 0%	59/59 100%	0/59 0%
5	Do you ever drink unfiltered water?	3/24 13%	21/24 88%	4/35 11%	31/35 89%	7/59 12%	52/59 88%
6 b	Do you filter this (cooking/washing hands/dishes) water?	1/24 4%	23/24 96%	0/35 0%	35/35 100%	58/59 98%	1/59 2%
6 c	Does the (cooking/washing hands/dishes) water appear turbid?	22/24 92%	2/24 8%	32/35 91%	3/35 9%	54/59 92%	5/59 8%
6 d	Is the water being stored in a covered container?	2/24 8%	22/24 92%	3/35 9%	32/35 91%	5/59 8%	54/59 92%

Questions 1a, 1b, and 3 were asked to ensure that the households were appropriately using functional filters. Of the 59 households surveyed, all were using functional filters. Question 5 asks if the households ever drink unfiltered water. A small percentage (12%) answered no to this question. Each of those households indicated that the reason they drink unfiltered water is because the *Kosim* filter is too slow to provide sufficient drinking water. Finally, Questions 6b, 6c, and 6d are subsets of Question 6, which asks, "Can you show me the water that you use for cooking/washing hands/dishes?" Therefore, these questions are referring to that cooking/washing hands/dishes water. In Question 6c, the surveyor observes whether or not the water used for cooking/washing hands/dishes appears turbid. For 54 of the 59 households, the water appeared turbid and was likely dugout water. However, of those five households that didn't have turbid water, four use piped water and the fifth purchases treated water, which is then stored in a tank.

Question 1c from the baseline survey is about how much water was in the *Kosim* plastic storage receptacle at the time of the baseline survey. On the 50 L storage receptacles (which are sold and distributed with the *Kosim* filter), there are 5 L marks along one side. These marks were used to approximate the volume of water in the vessel at the time of the survey.

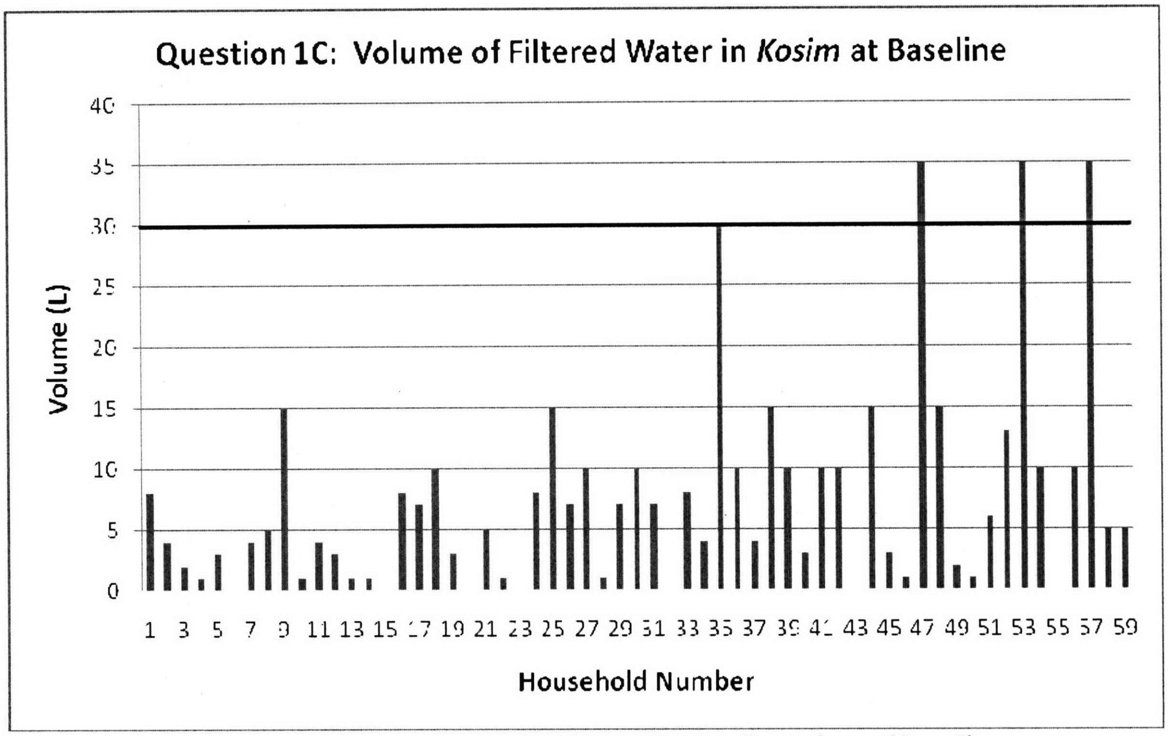


Figure 19: Volume of filtered water in *Kosim* receptacle at time of baseline survey.
*Line at 30L indicates the point to where the bottom of the ceramic filter extends into the storage receptacle

Several households were observed to be using the *Kosim* filter inappropriately by filling the filter to a point beyond its capacity. In these households, the water level of filtered water surrounded the ceramic pot, so that there was water above the level of the bottom of the filter (i.e. water inside and outside the pot). Figure 20 shows the point to which the ceramic pot extends into the storage receptacle. In these households, the water level had exceeded this 30 L point.

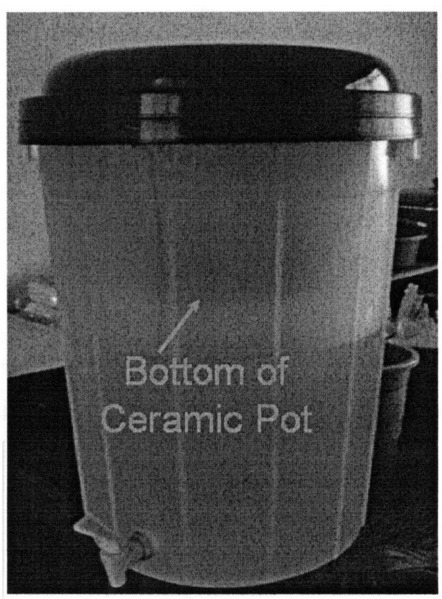


Figure 20: Point to which ceramic pot extends into storage receptacle.

Of the three households that had filtered water above the 30 L limit, two had removed the ceramic filter from the storage receptacle. The other household kept the ceramic filter in the storage receptacle, and continued to filter water[1]. Given that gravity is the driving force in the *Kosim* filter system, the filtered water inside the storage receptacle was at the same water level as the unfiltered water in the ceramic filter (to maintain equilibrium).

The average amount of water in the *Kosim* storage receptacle from the households surveyed in Kalariga was 3.9 L, with a standard deviation of 3.8 L. In Kakpagyili, there was an average of 10.1 L, with a standard deviation of 9.8 L. The two communities combined had an average volume of 7.2 L, with a standard deviation of 7.6 L. This data is relevant as 20 L of water are required in order to dose with Aquatabs.

Questions 2 and 6a from the "filter use" section of the baseline survey concern where the water for different household purposes comes from. The three different sources amongst the survey respondents were dugouts, piped water supply, and vended tanker truck water. Water source selection was fairly consistent among individual respondents (i.e. households in this study tend to use the same source, rather than using a combination of sources), which is largely a function of location/convenience and wealth.

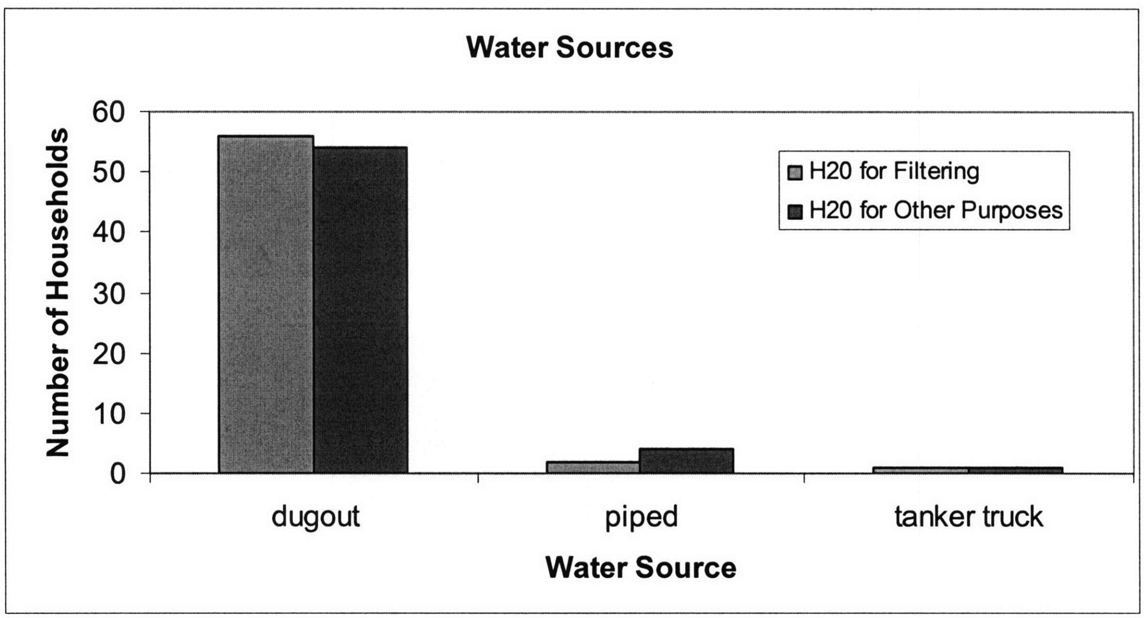


Figure 21: Water sources for all households surveyed. The blue columns indicate the number of households that use a particular source for *Kosim* filtering. The red columns indicate the number of households that use a particular source for cooking/washing hands/dishes.

[1] Household #47 water sample from the *Kosim* storage receptacle at baseline: turbidity=<5 TU, TC=<100 CFU/100mL, EC=<100 CFU/100mL

Dugouts have been explained previously. Piped water is water that is treated by the private consortium that is the Ghana Water Company Ltd. (GWCL) and is distributed to various communities by underground pipes[1]. The GWCL supplies water to 59% of urban areas in Ghana (Okioga, 2007). In Northern Region, Ghana, this water source is often unreliable. It is only available at certain times, and it is completely unavailable at a certain point in the later part of the dry season (March, April, May). In Tamale, it costs GHC 0.478/m^3 of water. Tank water is also treated by the GSCL and made available to local entrepreneurs who have trucks or tractors (displayed below) to haul it. In Tamale, it costs GHC 2.942/m^3 of water.

Figure 22: Tractor delivering treated tank water.

The breakdown of water sources by community is represented in the following table.

Table 16: Water Sources for Different Household Purposes

#	Question	Kalariga			Kakpagyili			Total		
	Water Source	D[a] #	P[b] #	T[c] #	D #	P #	T #	D #	P #	T #
2	From where do you collect your water (for *Kosim*)?	24	0	0	32	2	1	56	2	1
6a	Where does this water (cooking/cleaning hands/dishes) come from?	22	2	0	32	2	1	54	4	1

a – Dugout
b – Piped
c – Vendor Tanker Truck

[1] Piped water in Tamale is originally taken from the White Volta River. It is treated by the GWCL at the Dalun Water Treatment Plant, which is 35 km northwest of Tamale (Okioga, 2007). The water treatment processes involved are coagulation, flocculation, sedimentation, filtration, and disinfection. Once treated, 20,000 m^3/day is sent to 65% of Tamale.

These responses show that in both Kalariga and Kakpagyili households overwhelmingly obtained both their drinking and their cooking/cleaning water from dugouts.

Question 4 inquires how long the households have had their filters. This data varies for the two communities surveyed.

Table 17: Length of Times Households Have Been Using the *Kosim* Filters

#	Question	Kalariga				Kakpagyili
	Time	8 mo, #	1 yr, #	1 yr, 4 mo #	2 yr #	3 mo #
4	When did you purchase your filter?	5	16	2	1	35

All of the survey respondents from Kakpagyili received their filters 3 months prior to the baseline survey. In fact, at the time of the surveying in January, 2008, many of the households were still paying for their filters on a series of credit installments. While the survey respondents from Kalariga provided varying answers as to the length of time they had been using their *Kosim* filter, all of the Kalariga households received their filters in January, 2007, one year prior to the follow-up visit (Dia, 2007).

Finally, Question 7 asked the survey respondents how many times they added water to their filter per week. Respondents that indicated that they continually add water—or add water every day—to their *Kosim* filter were recorded as adding water 7 times per week.

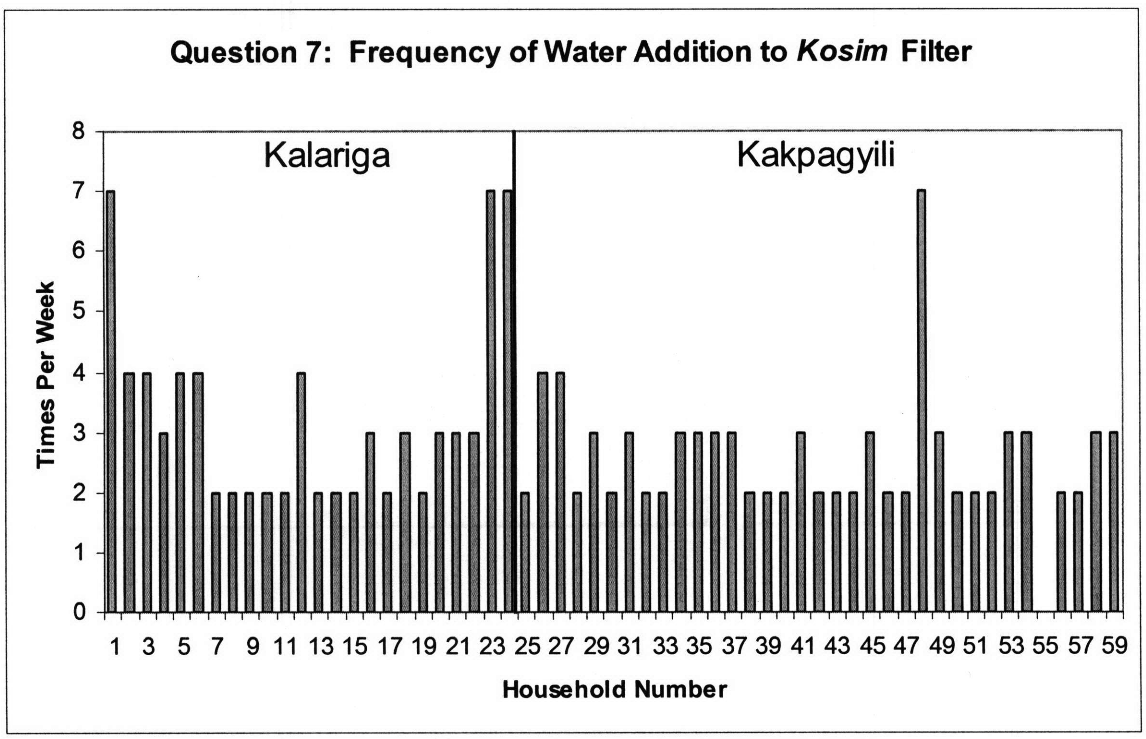


Figure 23: Frequency with which water is added to the *Kosim* filter.

In Kalariga, the average household fills their *Kosim* filter 3.3 times per week, with a standard deviation of 1.6. In contrast, households in Kakpagyili fill their filters 2.6 times per week, with a standard deviation of 1.1. This results in a total average of 2.9 times per week, with a standard deviation of 1.4.

This information is important—similar to Question 1c: volume of filtered water in *Kosim* at baseline—because it relates to the time needed to dose with Aquatabs. As previously discussed, the appropriate dosing protocol is one tablet for 20 L of water. Given that the ceramic portion of the *Kosim* filter is approximately 8-8.5 L, it requires 2-3 fillings in order to acquire a sufficient amount of water in the storage receptacle. If most households only fill their filters 2-3 times per week, then most households will only be able to treat approximately 20 L per week.

3.1.2 Filter Maintenance Survey Results

Questions 8-11 concern the maintenance of the filters. Specifically, Question 8 asks, "When was the last time you cleaned your filter and storage unit?"

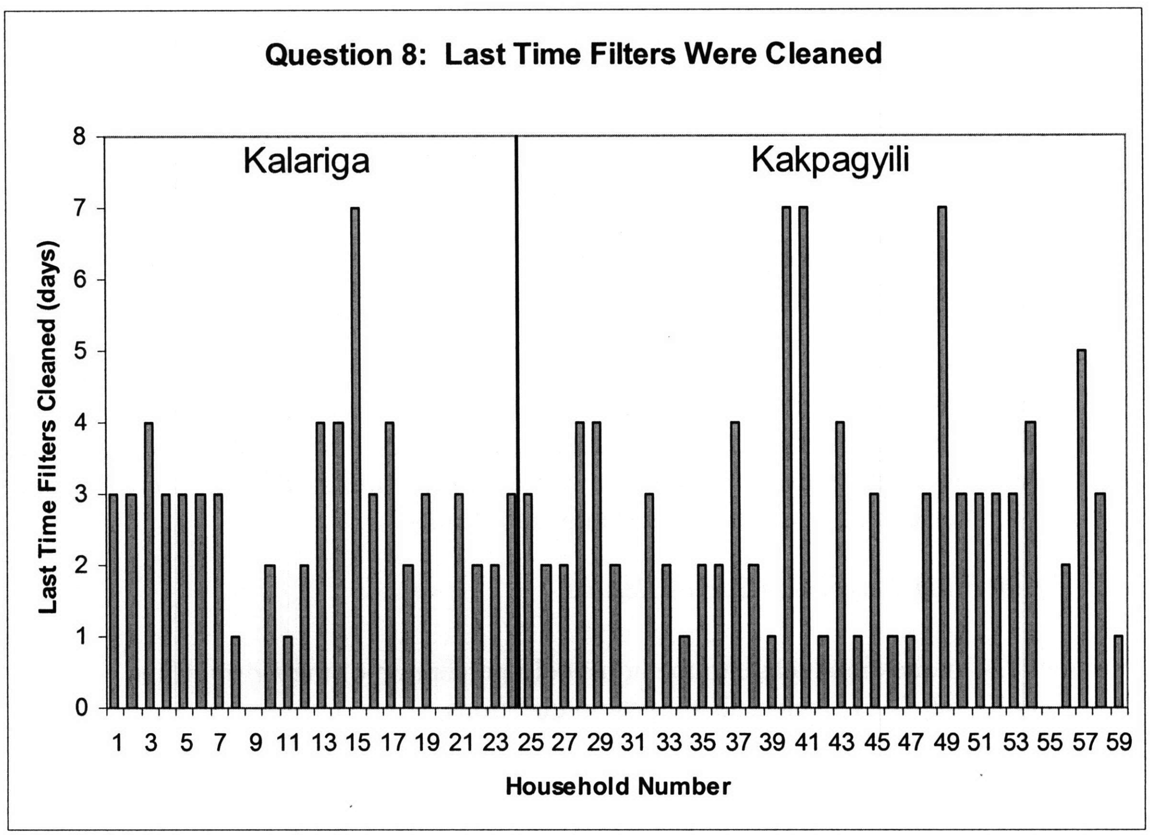


Figure 24: Last time household respondents cleaned their filters.

In Figure 24, values of 0 indicate that the filter was cleaned on the same day as the survey. However, household #55 was not using the filter at the time of the visit. The purpose of the study was explained to this household, which then indicated that they would begin using their filter if they could participate in the study.

In Kalariga, the average household last cleaned their filter 2.7 days previously, with a standard deviation of 1.5. In Kakpagyili, the average and standard deviation are 2.8 and 1.7 days, respectively. The average and standard deviation for all respondents is 2.8 and 1.7 days. Additionally, 45 of the 59 households (76%) cleaned their filters within three days prior to the time of the survey.

Questions 9, 9a, 10, 11a, 11b, and 11c are yes/no questions. Because the responses did not vary significantly among the two communities, only the total results have been tabulated.

Table 18: Yes/No Responses for Baseline Survey Maintenance

#	Question	Total	
		Yes	No
9	Did the sales person give you materials to explain how to clean the filter?	59/59=100%	0/59=0%
9 A	If yes, can you please show me these materials?	57/59=97%	2/59=3%
10	Did this person come to your house and show you how to clean the filter?	59/59=100%	0/59=0%
11 A	Do they use the provided brush?	57/59=97%	2/59=3%
11 B	Did they clean the storage unit?	59/59=100%	0/59=0%
11 C	Did they use soap and filtered water to clean the storage unit?	59/59=100%	0/59=0%

Nearly the entire yes/no responses in this section were consistent. The only discrepancies were amongst responses from two households in Kalariga, who did not have brushes. As a result, they were unable to show the materials that they used for cleaning, and they did not use the brush in demonstrating how they cleaned their filters. Brushes were supplied to these two households to ensure consistent study results.

3.1.3 Kosim Filter Perception Survey Results

The final 12-16 questions relate to the household perception of the *Kosim* filter. Questions 12, 13, 14, 15, and 15b are yes/no questions.

Table 19: Yes/No Responses for Baseline Survey Perception

#	Question	Kalariga		Kakpagyili		Total	
		Yes	No	Yes	No	Yes	No
12	Do you like the taste of the filtered water?	24/24 100%	0/24 0%	35/35 100%	0/35 0%	59/59 100%	0/59 0%
13	Is the filter easy to use?	21/24 88%	3/24 13%	30/35 86%	5/35 14%	51/59 86%	8/59 14%
14	Have you had any problems with the filter breaking?	5/24 21%	19/24 79%	0/35 0%	35/35 100%	5/59 14%	54/59 86%
15	Before you got the filter, did you treat the water at all?	24/24 100%	0/24 0%	35/35 100%	0/35 0%	59/59 100%	0/59 0%
15 b	Did that work (previous treatment)?	24/24 100%	0/24 0%	35/35 100%	0/35 0%	59/59 100%	0/59 0%

In Question 13, when the survey respondents were asked if the filter is easy to use, 14% indicated that it is not because it is too slow. Furthermore, the percentage of people who felt that way was consistent among the two communities surveyed. 13% of people in Kalariga felt that the filters were too slow and 14% of people from Kakpagyili. Additionally, only five people had problems with their filter breaking, and all five of those people were from Kalariga. Two households had cracked storage receptacles. One receptacle was cracked on the bottom, and another was cracked around the hole for the tap. Another household had a cracked lid, another a cracked ceramic filter and the fifth had a broken tap. All of these breakages occurred in Kalariga, who had their filters four times as long as the people from Kakpagyili.

In Question 15, when the respondents were asked, "Before you got the *Kosim* filter, did you treat the water at all?" every household indicated that they did. This is because of the Guinea Worm Eradication Program in Tamale. This initiative distributed free cloth filters to every household. Of the 59 households surveyed, all 59 previously used the cloth filter and 4 of the 59 households previously used alum in addition to the cloth filter to treat their water. Three of these households were in Kalariga, and one in Kakpagyili. Furthermore, in Question 15b the respondents were asked if their previous treatment method "worked". Every one of the households indicated that their previous treatment method worked, however 7 (3 in Kalariga and 4 in Kakpagyili) of the households indicated—without being prompted—that it was "not as good" as the *Kosim* filter.

Question 16 (the last question) asked, "When was the last time someone in your house had diarrhea?" Of the 59 households surveyed, 14 could remember the last time someone had diarrhea.

Table 20: Diarrhea History of Households Surveyed

Community	Household #	Last Time Someone Had Diarrhea	Age of Person with Diarrhea
Kalariga	5	Yesterday	15
Kalariga	6	1 wk	2
Kalariga	7	2 mo	50
Kalariga	15	2 wk	30
Kalariga	23	1 wk	45
Kakpagyili	25	1 mo	40
Kakpagyili	26	6 mo	50
Kakpagyili	27	5 mo	40
Kakpagyili	28	3 mo	2X40, 2X10
Kakpagyili	29	1 mo	5
Kakpagyili	31	2 wk	4
Kakpagyili	49	1 wk	2X40, 1X5
Kakpagyili	55	1 wk	7
Kakpagyili	59	3 wk	4

3.2 Follow-up Survey Results

The follow-up survey consists of 8 questions, 6 of which are yes/no type questions. There was no variation in responses between the 2 communities surveyed, so the results were combined.

Table 21: Yes/No Responses to Follow-up Survey

#	Question	Total	
		Yes	No
1	Did you use the provided Aquatabs to treat your water?	59/59 100%	0/59 0%
3	Did the Aquatabs improve the taste of the water?	59/59 100%	0/59 0%
4	Are the Aquatabs easy to use?	59/59 100%	0/59 0%
5	Have you had any problems using the Aquatabs?	0/59 0%	59/59 100%
7	Would you recommend the use of Aquatabs to others?	59/59 100%	0/59 0%
8	Has anyone in your household had diarrhea recently?	0/59 0%	59/59 100%

These results will be explained further in the following sections.

3.2.1 Filter and Aquatabs Use Survey Results

A subset of Question 1 ("Did you use the provided Aquatabs to treat your water?") was Question 1b, an observational question relating to how much water was in the jerry can at the time of the visit. This question combined with Question 2, "How many times in the past week have you used Aquatabs?" gives an indication as to how much chlorine disinfected water each household consumed in the week between the baseline survey and the follow-up survey.

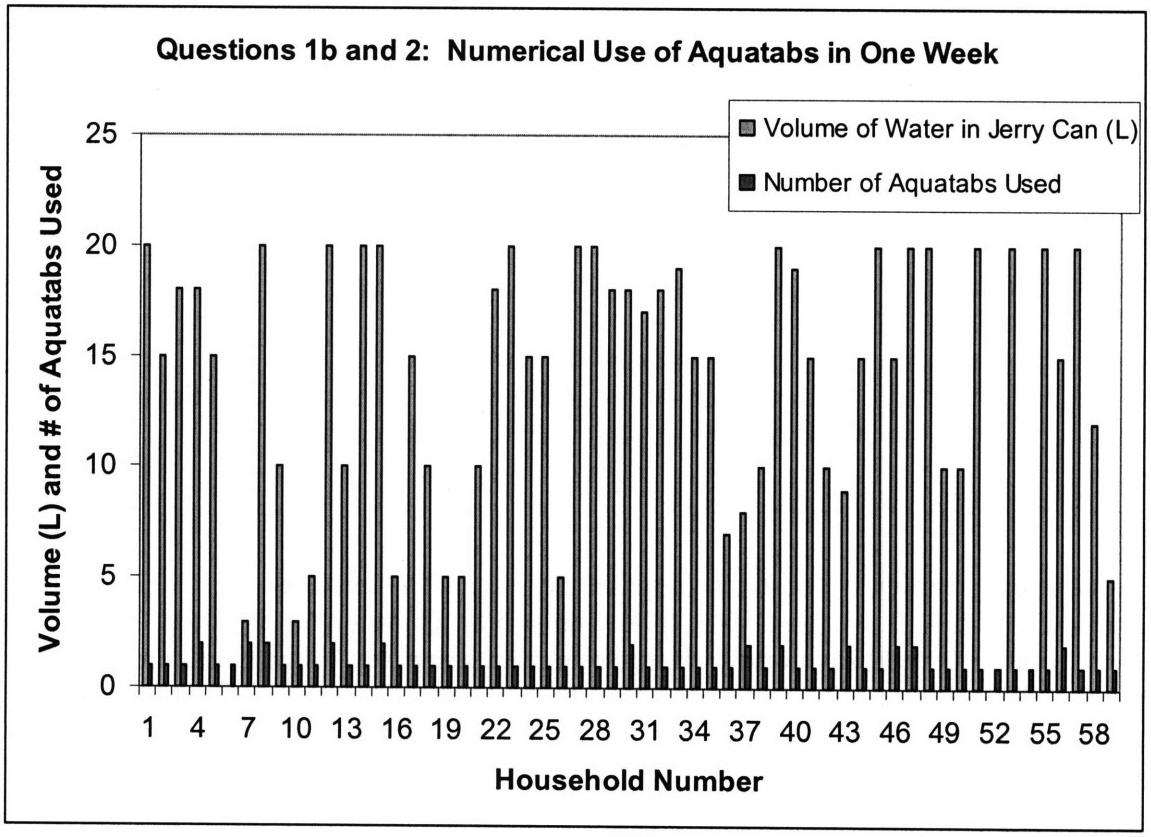


Figure 25: Use of Aquatabs over one week. The blue columns represent the amount of water in the jerry cans at the time of the follow-up visit. The red columns indicate the number (either 1 or 2) of Aquatabs used.

From Figure 25, it is clear that Household #1 consumed no treated water in the week between the baseline survey and the follow-up survey. This is because they used only one Aquatab and had 20 L of treated water available. Therefore, no water was consumed. This is contrasted with Household #37, which used two Aquatabs and had only 8 L of water in their jerry can. This indicates that this particular household dosed 20 L of water, consumed all of that treated water, dosed an additional 20 L of water, and consumed 12 L of that treated water. Therefore, this household consumed 32 L of water compared to the 0 L of water consumed by Household #1.

Furthermore, no household used more than two Aquatabs in the week between the baseline survey and the follow-up survey. At this usage rate, 104 Aquatabs would be sufficient for one household for an entire year.

3.2.2 Filter and Aquatabs Perception Survey Results

All 59 of the 59 households surveyed answered "yes" when asked if the Aquatabs "improved the taste of the water". In fact, four households in Kakpagyili indicated that the chlorinated water tasted like "pure water". "Pure water" is the local term for highly treated and expensive form of water sold in 500 mL heat sealed, plastic bags. It is roughly equivalent to bottled water brands. Furthermore, every household said that they would recommend Aquatabs to others. In fact, one survey respondent said that she had just recommended Aquatabs to her friend that same day.

However, while every household indicated that the Aquatabs were easy to use, and that they had never experienced problems using Aquatabs (see Table 21), a number of households revealed displeasure with the product. One woman in Kalariga said that she was "not comfortable when she took (consumed) Aquatabs". Another man in Kalariga claimed that a recently developed hernia was caused by the Aquatabs. He also said that the Aquatabs turned his urine more yellow. Finally, one woman in Kakpagyili said that she had experienced stomach aches as a result of taking Aquatabs.

3.2.3 Cost of Aquatabs Survey Results

As mentioned earlier, Medentech charges GHC 3 for 100 Aquatabs. This is nearly the equivalent of US $3. As part of the follow-up survey, Question 6 was asked, "Would you spend GHC 3 for 100 Aquatabs?" If the respondents said "no", then Question 6b was asked, "What do you think a fair price for 100 Aquatabs is?" This question is important in determining whether this product can be sold at market value, and thus how sustainable of a technology it is.

The response between the two communities was drastically different. In the poorer community of Kalariga, only 6 of the 24 households (25%) indicated that they were willing to pay GHC 3 for 100 Aquatabs.

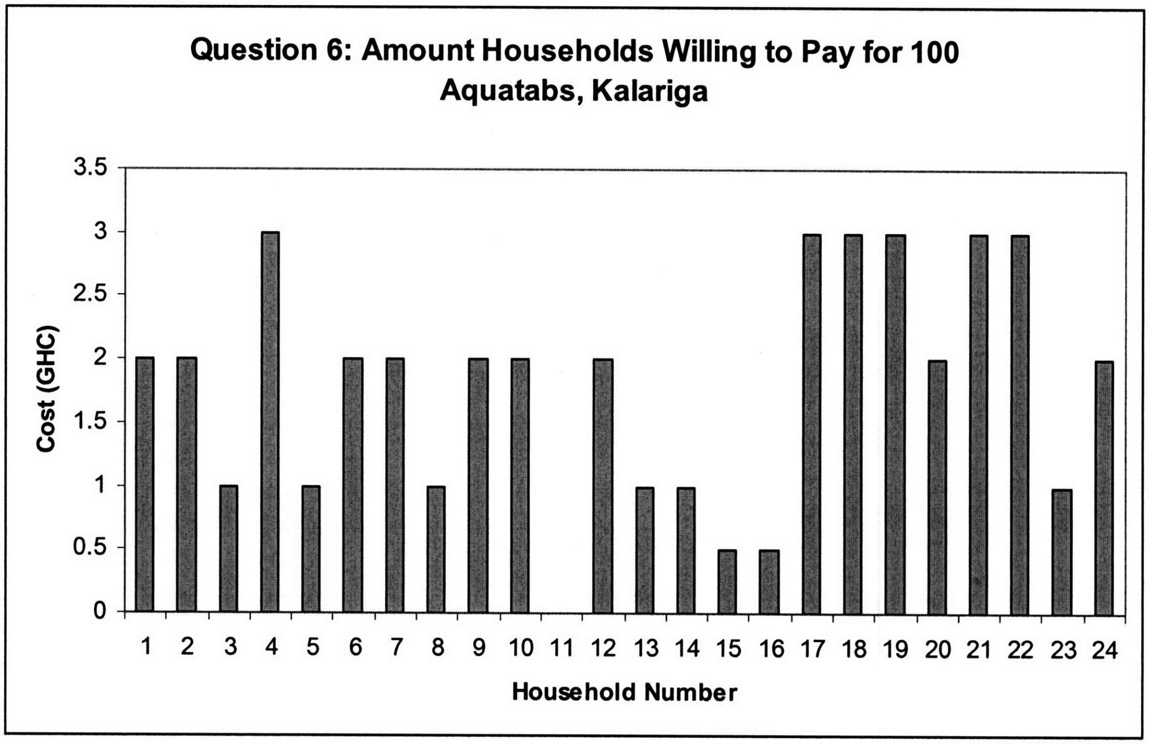


Figure 26: Amount Kalariga community members willing to pay for 100 Aquatabs.

The average amount that community members in Kalariga were willing to pay was GHC 1.8 for 100 Aquatabs, with a standard deviation of GHC 0.9. These results are strongly contrasted with the response from the lower middle class community of Kakpagyili. In Kakpagyili, 33 of the 35 households (94%) expressed willingness to pay the full GHC 3. Of the two households who were unwilling, one suggested GHC 2 and the other GHC 1.

3.3 Kalariga and Kakpagyili Household Profiles from Survey Results

Based on all the surveyed responses from the two communities, Kalariga and Kakpagyili, the following profiles of the "typical" survey respondent can be derived.

Table 22: Household Profiles For Kalariga and Kakpagyili from Survey Results

#	Question	Kalariga	Kakpagyili
	Baseline Survey		
1	Can you show me the water you use for drinking?		
a	Is the ceramic filter installed in the unit?	yes	yes
b	Is the filter covered with a lid?	yes	yes
c	How much water is in the receptacle? (L)	4	10
2	From where do you collect your water?	dugout	dugout
3	Is your filter working?	yes	yes
4	When did you purchase your filter?	1 yr	3 months
5	Do you ever drink unfiltered water?	no	no
a	If yes, why?		
6	Can you show me the water you use for		

	cooking/cleaning/doing dishes?		
a	Where does this water come from?	dugout	dugout
b	Do you filter this water?	yes	yes
c	Does the water appear turbid?	yes	yes
d	Is the water being stored in a covered container?	no	no
7	How many times per week do you add water to the filter?	3.3	2.6
8	When was the last time you cleaned the filter? (days)	2.7	2.8
9	Did the sales person give you materials to explain how to clean the filter?	yes	yes
a	If yes, can you please show me these materials?	yes	yes
10	Did this person come to your house and show you how to clean the filter?	yes	yes
11	Can you act our for me how you clean the filter?		
a	Do they use the provided brush?	yes	yes
b	Did they clean the storage unit?	yes	yes
c	Did they use soap and filtered water to clean the storage unit?	yes	yes
12	Do you like the taste of filtered water?	yes	yes
13	Is the filter easy to use?	yes	yes
14	Have you had any problems with the filter breaking?	no	no
a	If yes, can you show me what the problem is/was?		
15	Before you got the filter, did you treat the water at all?	yes	yes
a	If so, how?	cloth	cloth
b	Did that work?	yes	yes
16	When was the last time someone in your house had diarrhea?	?	?
a	How old was this person? (yrs)		
Follow-up Survey			
1	Did you use the provided Aquatabs to treat your drinking water?	yes	yes
a	If no, why not?		
b	How much water in Jerry Can? (L)	12.5	14.3
2	How many times in the past week have you used the Aquatabs	1.2	1.2
3	Did the Aquatabs improve the taste of the water?	yes	yes
4	Are the Aquatabs easy to use?	yes	yes
5	Have you had any problems using the Aquatabs?	no	no
6	Would you spend 3GHC for 100 Aquatabs?	no	yes
a	If no, what do you think a fair price for 100 Aquatabs is?	1.4	
7	Would you recommend the use of Aquatabs to others?	yes	yes
8	Has anyone in your household had diarrhea recently?	no	no
a	If yes, how old?		

3.4 Water Quality Results

The complete household-by-household water quality test results are included in Appendix G. Households in this thesis are referred to as household #'s 1-59, where household #'s 1-24 are the 24 households in Kalariga and household #'s 25-59 are the 35 households in Kakpagyili.

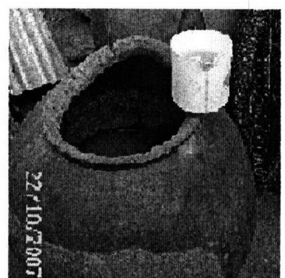
With this treatment system, for households that collect water from dugouts, there are four stages in the water treatment process. The first is the origin of the water in the dugouts. Households collect this water in metal/plastic buckets/containers and store it in their households in large, ceramic, pre-treatment, storage vessels. Each household has roughly 2-5 of these vessels, from which water is taken and added to the *Kosim* filter. Afterwards, the filtered water is emptied into the 20 L jerry cans and dosed with Aquatabs.

As mentioned previously, in this section <5 TU are averaged and presented in graphs as 2.5 TU. Furthermore, TC and EC values of <100 CFU/100mL are averaged and presented in graphs as 50 CFU/100mL.

Dugout

	n	Turbidity (NU)	TC (CFU/100mL)	EC (CFU/100mL)
Kalariga	1	400	6,200	67
KakDam1	1	400	11,000	<100
KakDam2	1	1200	23,000	1,000

Pre-Treatment, Stored Water



	n	Turbidity (NU)	TC (CFU/100mL)	EC (CFU/100mL)
Kalariga	1	150	5,000	100
Kakpagyili	2	200	6,000	<100
Total	3	180	5700	67

Post-Filtered

	n	Turbidity (NU)	TC (CFU/100mL)	EC (CFU/100mL)
Kalariga	24	16	2,200	61
Kakpagyili	35	17	2,900	60
Total	59	16	2,600	60

Post-Aquatabs

	n	Turbidity (NU)	TC (CFU/100mL)	EC (CFU/100mL)
Kalariga	24	11	2,000	<100
Kakpagyili	35	38	900	110
Total	59	27	1,300	86

Figure 27: Summary of averaged water quality testing results.

Figure 27 displays the primary water quality test results in the four stages of the water treatment process: from the source at the dugout, to being stored in pre-treatment ceramic vessels, after the water has been filtered through the *Kosim* filter and after the water has been dosed with Aquatabs. The number column ("n") with each of the four sets of data indicates the number of tests taken for that data set in that particular community. There are only one or several data points for the dugout and pre-treatment stored water. The focus of the author's water quality testing was the post-filtering and post-Aquatabs water samples from the 59 houesholds surveyed.

The averaged turbidity results also include two households that used piped water supply and one household that purchases vendor tanker truck water, all three of which had no turbidity in the pre-treatment, stored samples (these household's water quality results are only included in the "after filtering" and "after Aquatabs" sections of Figure 27). The three dams used by Kalariga and Kakpagyili are highly turbid and microbially contaminated. Kalariga Dam had a turbidity of 400 TU, a TC value of 6,200 CFU/100mL, and an EC value of 400 CFU/100mL. In Kakpagyili, KakDam1 and KakDam2 had turbidity values of 400 TU and 1,200 TU, respectively. KakDam1 has a TC value of 1,100 CFU/100mL and an EC value of <100 CFU/100mL. KakDam2 has a TC value of 23,000 CFU/100mL and an EC value of 1,000 CFU/100mL. Both of these microbial results are based on one 3M Petrifilm™ test per dugout.

The pre-treatment, stored water quality test results from dugouts are based on three samples, one from Kalariga and two from Kakpagyili. While performing field work, various pre-treatment stored water samples were taken for comparison with the dugouts, as shown in Table 23.

Table 23: Pre-Treatment Stored Water Quality Test Results

Household #	Community	Water Source	Turbidity (TU)	TC (CFU/100mL)	EC (CFU/100mL)
20	Kalariga	Dugout	150	5,000	100
29	Kakpagyili	Dugout	400	8,000	<100
48	Kakpagyili	Piped	<5	2,000	<100
50	Kakpagyili	Dugout*	<5	4,000	<100
52	Kakpagyili	Tanker Truck	<5	12,000	<100

*Pre-treatment stored water was treated with alum, which explains low turbidity

The reason that the pre-treatment, stored water from household #50 has such a low turbidity coming from a dugout is because this household uses alum prior to filtering, to settle out particulates. In this household's pre-treatment storage vessel, the water was clear, and there was a pile of settled particulates at the bottom. Furthermore, only the pre-treatment test results from households 20, 29, and 50 are included in Figure 27, in order to compare the water quality of the various stages of treatment for the dugout water alone. One cannot draw decisive conclusions based upon such a small sample size.

The following figures show the averaged water quality results from all households sampled.

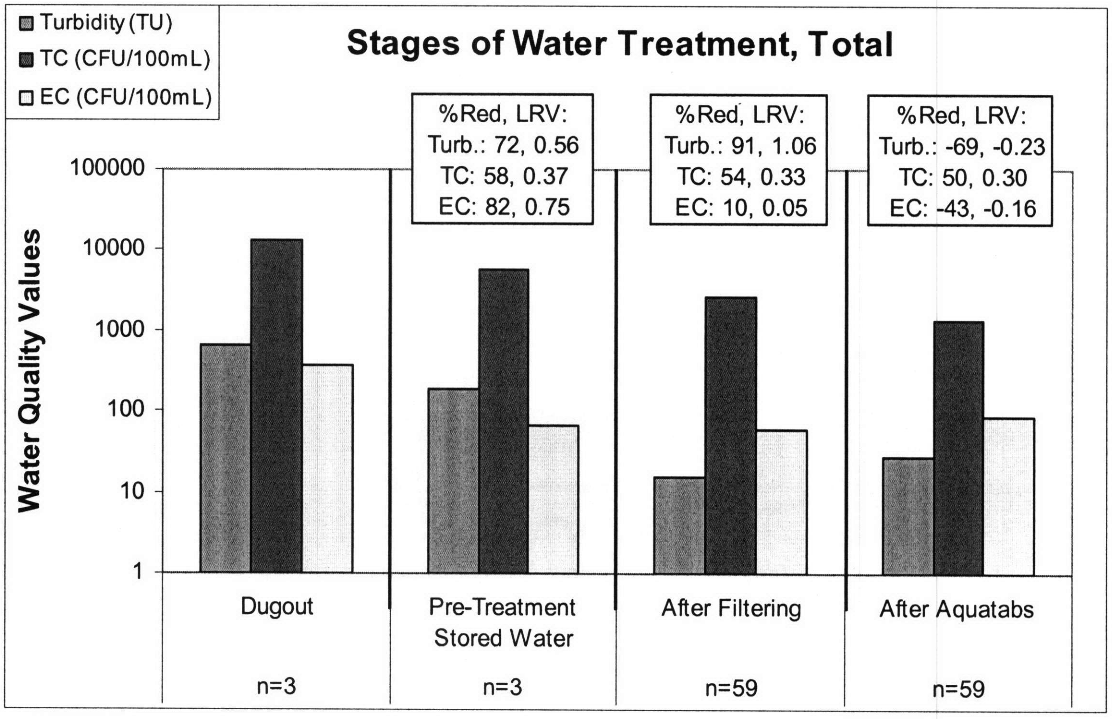


Figure 28: Average water quality data at various stages of treatment for all data in both communities. The bars depict values of the three water quality parameters (turbidity, TC, EC). The "%Red, LRV" boxes indicate the percent reductions and log removal from stage-to-stage, rather than from dugout-to-stage. "Turb." refers to turbidity.

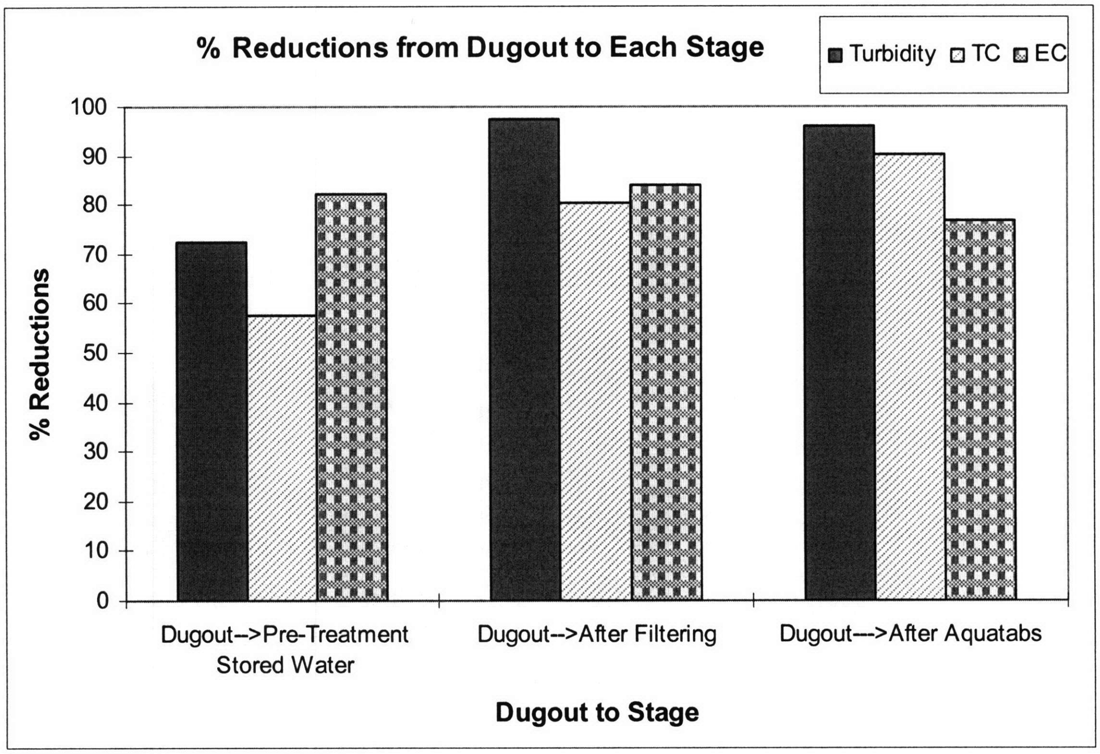


Figure 29: The bars depict % reductions from dugout to stage for pre-treatment stored water, after filtering, and after Aquatabs stages.

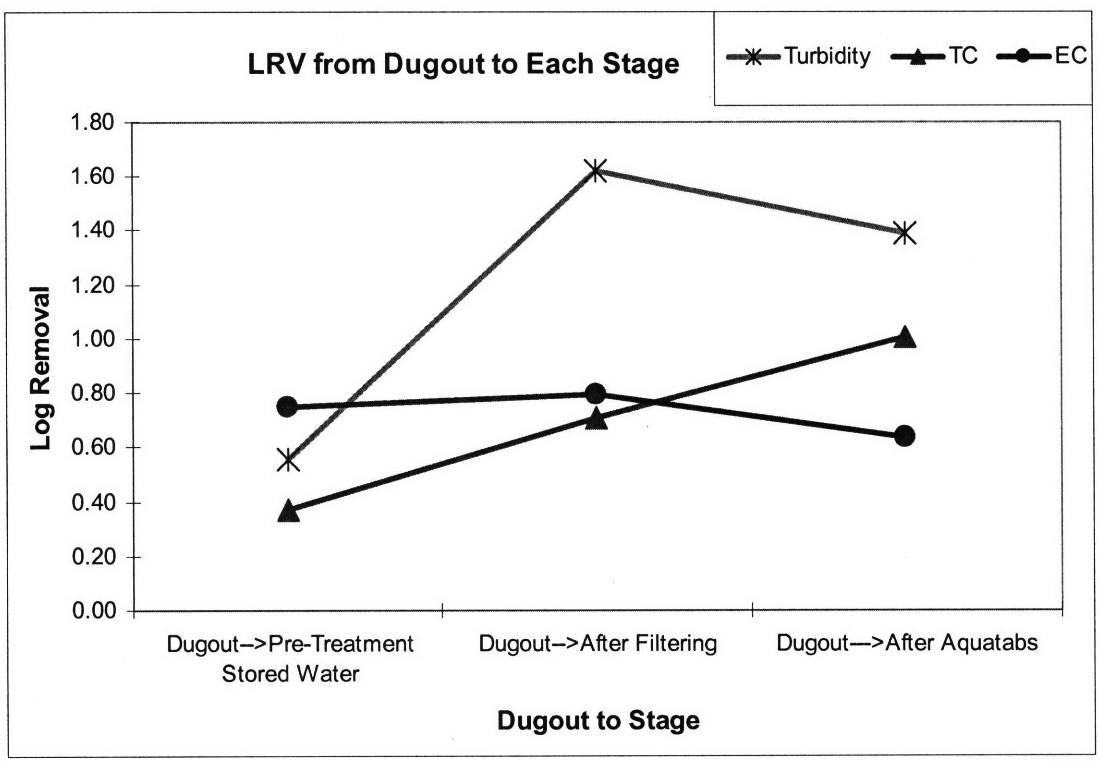


Figure 30: The lines depict log removal from dugout to stage for pre-treatment stored water, after filtering, and after Aquatabs stages.

The following figures show the averaged water quality values for each community.

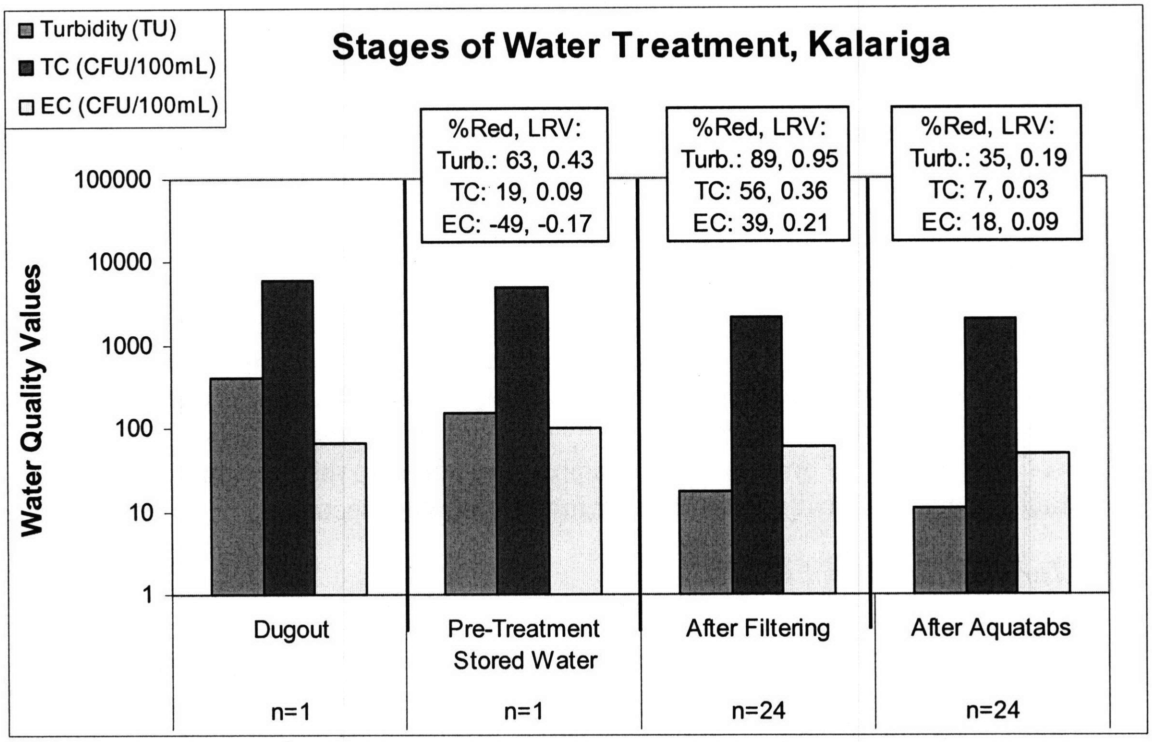


Figure 31: Kalariga water quality data at various stages of treatment.

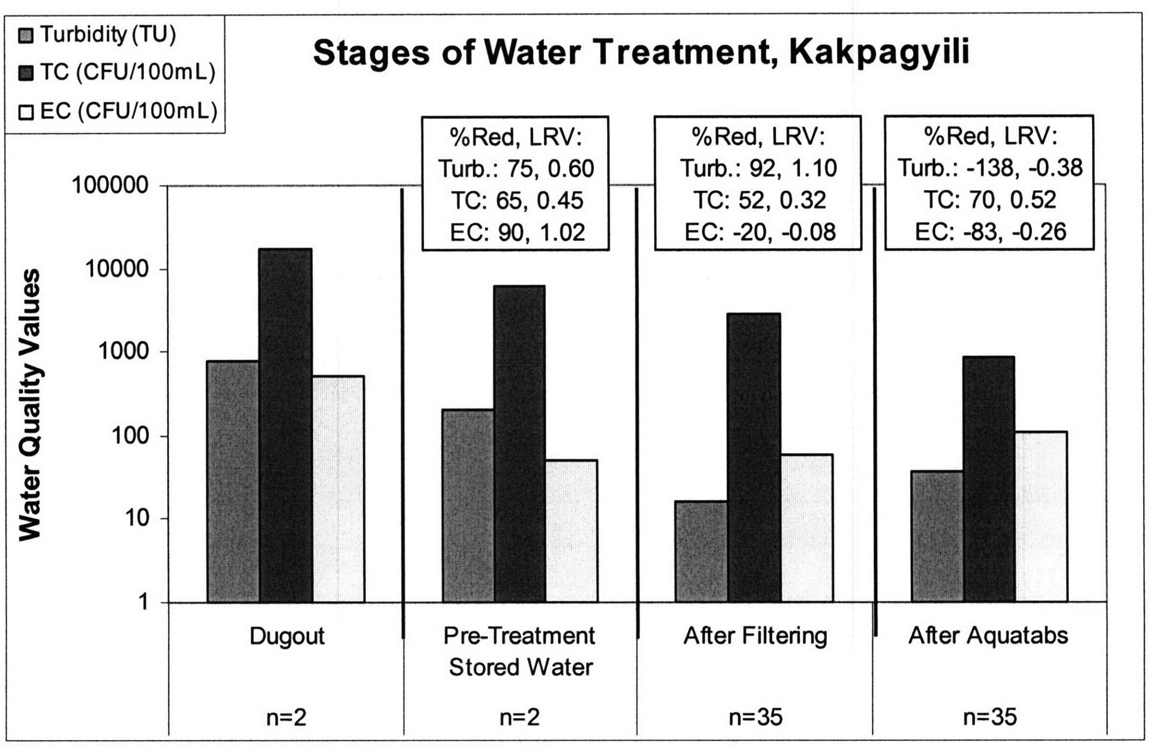


Figure 32: Kakpagyili water quality data at various stages of treatment.

It is noteworthy that the turbidity test results indicate a decrease of 72% (63% and 75% for Kalariga and Kakpagyili, respectively) from the dugout to the pre-treatment storage vessel. This decrease is likely due to the natural settling of particulates (aided in household #50 by the application of alum). Additionally, there are 19% and 65% reductions in TC concentration from the dugouts to the pre-treatment storage vessels in Kalariga and Kakpagyili, respectively. This is a significant reduction, which shows the wisdom of simple, indigenous, household water management practices.

The water quality data from the filtered-only and from the filtered and chlorine disinfected water will be presented more thoroughly in the following sections. However, from the pre-treatment, stored water to the filtered-only water; there are 91%, 54%, and 10% reductions in turbidity, TC, and EC respectively. Furthermore, from the filtered-only water to the filtered and chlorine disinfected water, the TC count is reduced by 50%, while the turbidity and EC values increase by 69% and 43%, respectively. These increases are unexpected because the Aquatabs were added to disinfect the water. Nevertheless, this will be discussed further in the following sections.

3.4.1 Turbidity Test Results

Turbidity was tested to determine if the *Kosim* filters were effectively removing the suspended particulates from the water sources. As described previously, bacteria in the water sources has a tendency to bind to the suspended particles, which interferes with the chlorination process. The turbidity of the treated water was measured during the baseline survey (filtered-only) and the follow-up survey (filtered and chlorine disinfected). Using a turbidity tube, the lowest possible turbidity reading is <5 TU. These values are displayed in the following graphs as 2.5 TU.

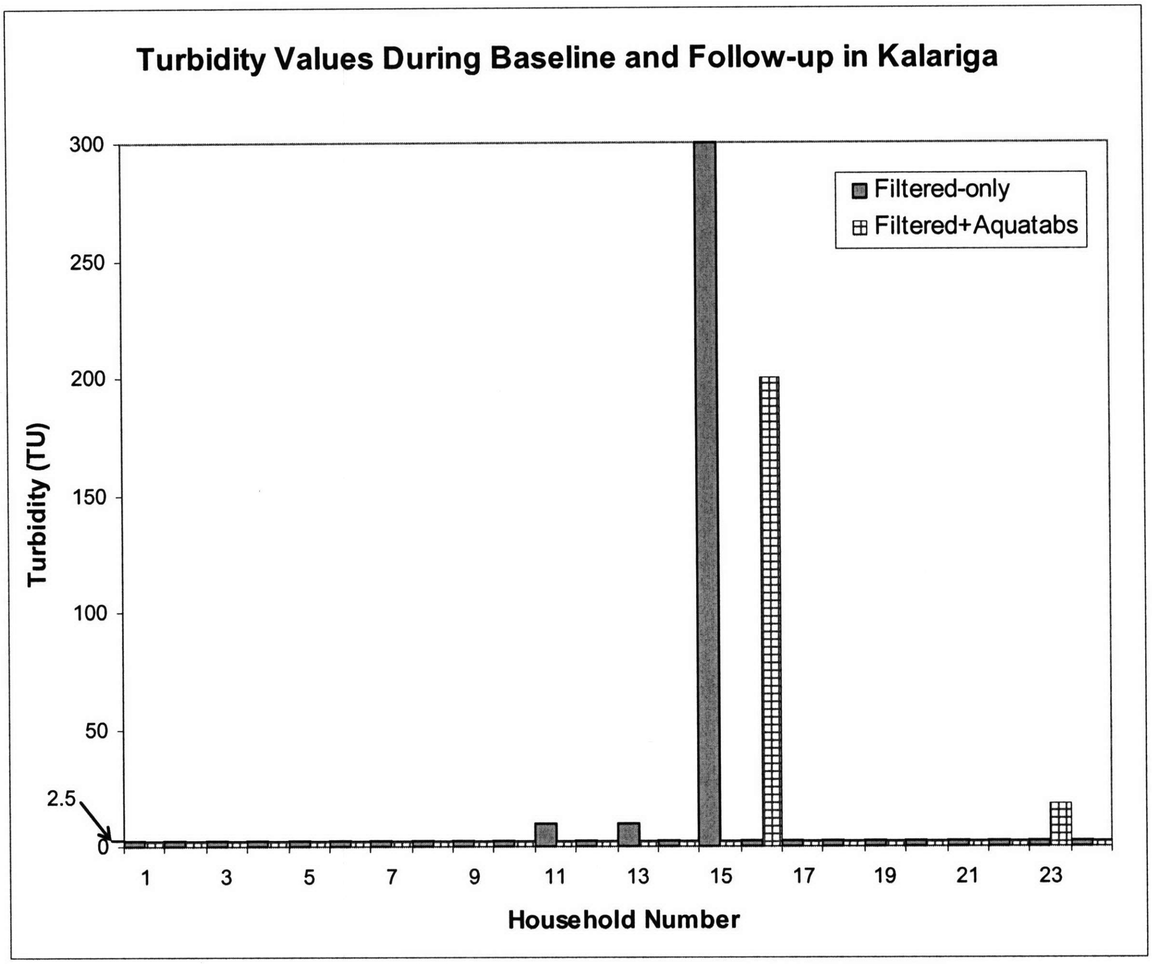


Figure 33: Turbidity test results during baseline and post-intervention in Kalariga.

For the filtered-only water, 21 of the 24 households (88%) in Kalariga had a turbidity value <5 TU. Of the three households >5 TU, two households had a turbidity value of 10 TU and the third had a turbidity value of 300 TU. For the filtered and chlorine disinfected water, 22 of the 24 households (92%) had a turbidity value <5 TU. Between the two households with a turbidity value >5 TU, one had a turbidity value of 18 TU and the other 200 TU. Furthermore, these two households were not the same as any of the three filtered-only households that had a turbidity >5 TU.

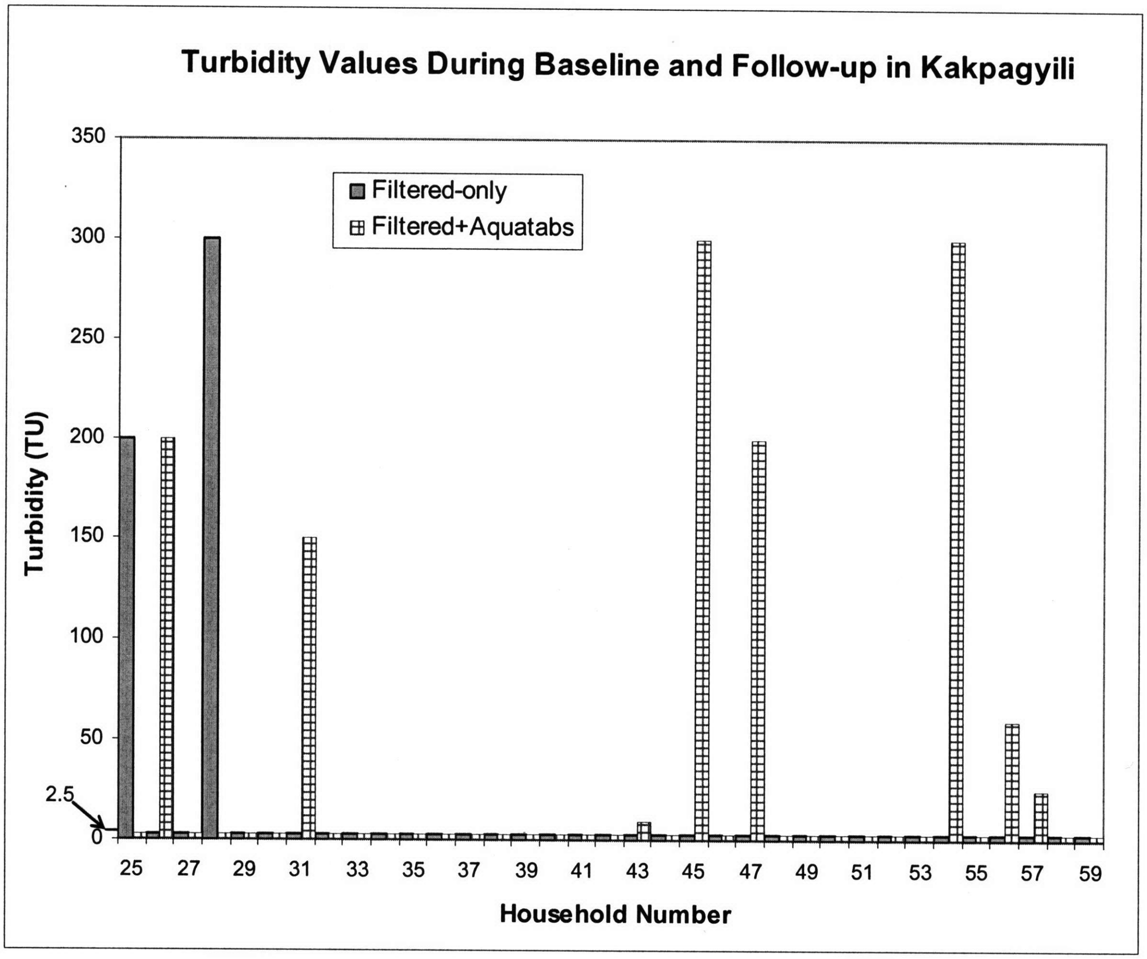


Figure 34: Turbidity test results during baseline and post-intervention in Kalariga.

For the filtered-only water in Kakpagyili, 33 of the 35 households (94%) had a turbidity value <5 TU. The two households >5 TU had values of 200 and 300 TU. For the filtered and chlorine disinfected water in Kakpagyili, 27 of 35 households (77%) had turbidity values <5 TU. The eight households >5 TU had values of 10, 25, 60, 150, 200 and 300 (twice) TU. Similar to Kalariga, none of the two filtered only households >5 TU were the same as any of the eight filtered and chlorine disinfected households >5 TU.

3.4.2 Microbial Test Results

Microbial tests were performed on each household during the baseline survey and follow-up survey, in order to compare the microbial contamination of filtered water with filtered water dosed with Aquatabs. Results are reported in CFU/100mL (i.e. the number of colony-forming units in 100 mL of water sample). As discussed previously, using 3M Petrifilm™ testing materials, even when no colonies are detectable on the incubated plate, the lowest possible measurement for TC and EC contamination is <100 CFU/100mL. In the graphs in this section, values of <100 CFU/100mL are reported as 50 CFU/100mL. Additionally, for all averaged microbial values in this thesis, measurements of <100 CFU/100mL were treated as 50 CFU/100mL.

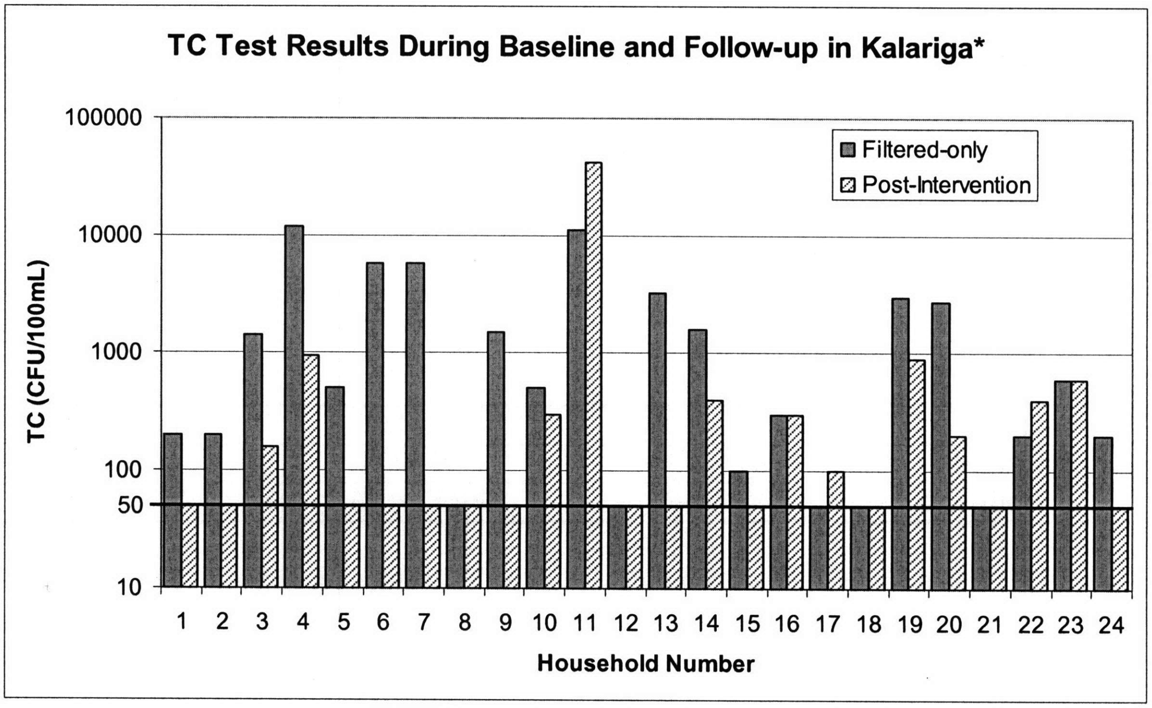


Figure 35: TC test results before (filtered-only) and after (filtered+Aquatabs) the use of Aquatabs in Kalariga (log-scale).

*Line at 50 CFU/100mL signifies the measurements with values <100 CFU/100mL

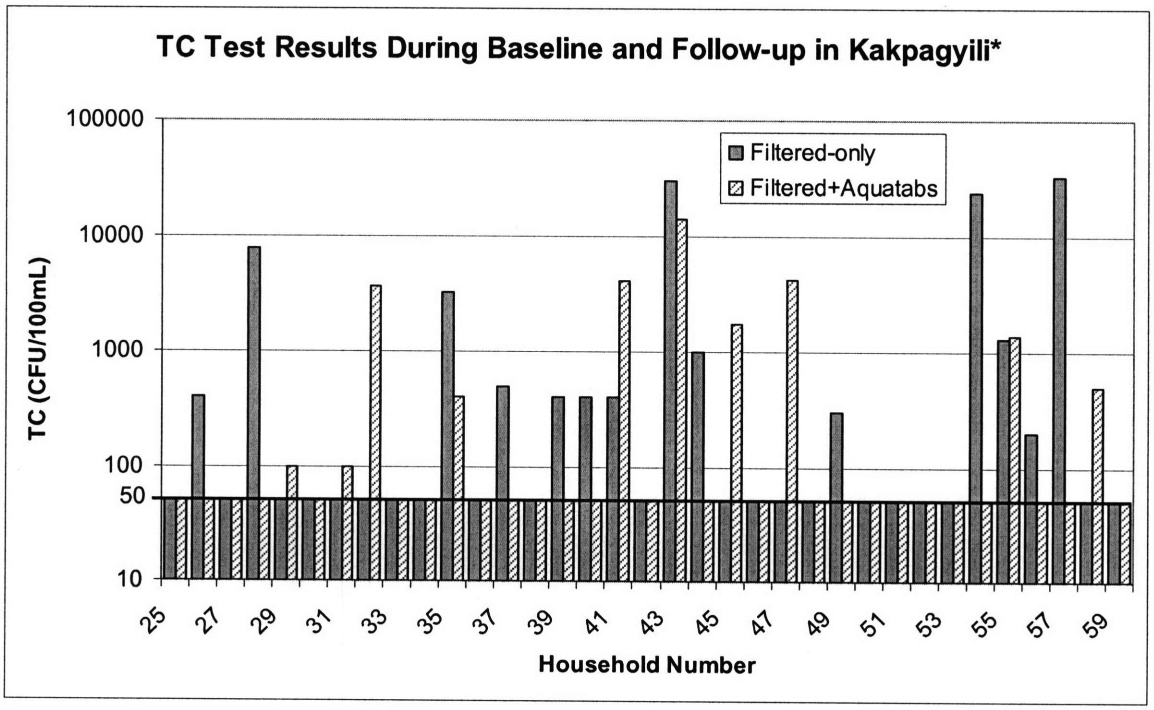


Figure 36: TC test results before (filtered-only) and after (filtered+Aquatabs) the use of Aquatabs in log-scale in Kakpagyili (log-scale).

*Line at 50 CFU/100mL signifies the measurements with values <100 CFU/100mL

Table 24 shows the percentage of households that had decreased microbial contamination, compared with households with increased microbial contamination before and after using Aquatabs.

Table 24: Decreasing/Increasing TC Contamination Trends amongst Communities Before and After Using Aquatabs

Community	TC Count Decreased	TC Count Increased	TC Count Remained the Same
Kalariga	15/24=63%	3/24=13%	6/24=25%
Kakpagyili	12/35=34%	7/35=20%	16/35=46%
Both	27/59=46%	10/59=17%	22/59=37%

Figure 35, Figure 36 and Table 24 indicate that the TC values for individual households mostly decrease (46%) as a result of using Aquatabs. However, household #11 and #41 had 280% and 925% increases in TC, and household #'s 17, 31, 32, 45, 47, and 58, which had <100 CFU/100mL TC counts from the filtered only water, all indicated the presence of TC in the filtered and chlorine disinfected water. On the other hand, 46% of the households surveyed had decreased TC counts and 37% remained the same. And household #'s 6, 7, 28, 54, and 57, which had TC counts in excess of 5,000 CFU/100mL after filtration only, were all reduced to <100 CFU/100mL after filtration and Aquatabs.

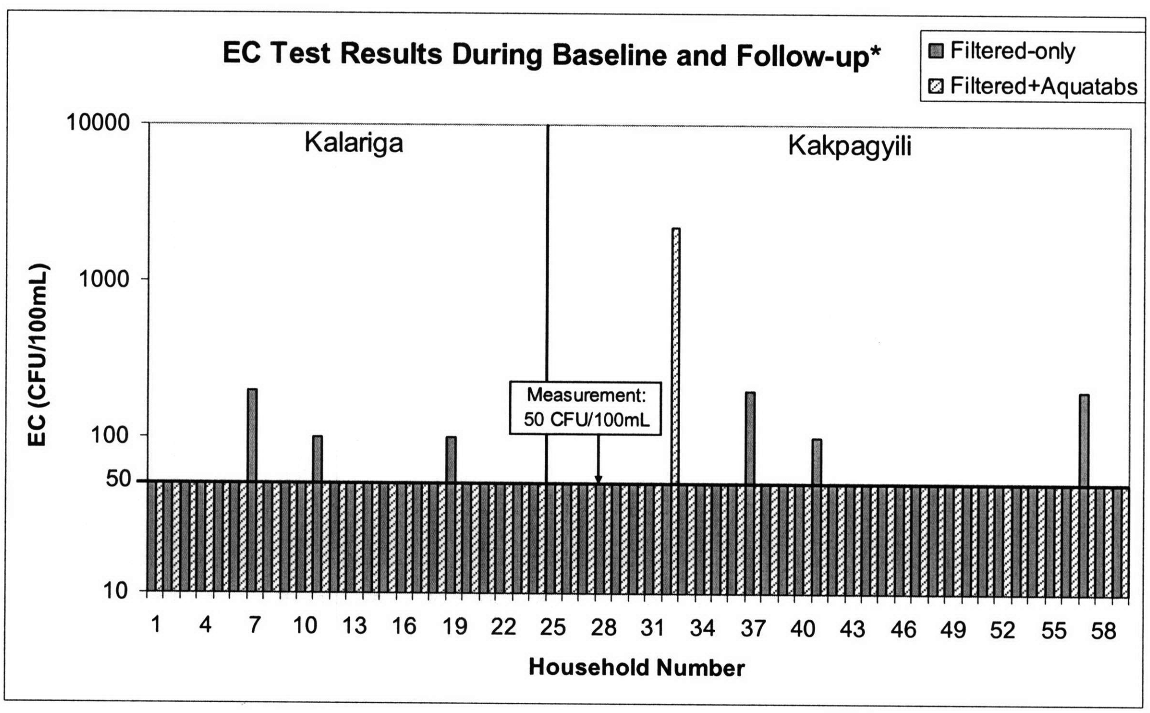


Figure 37: EC test results before (filtered-only) and after (filtered+Aquatabs) the use of Aquatabs (log-scale).

*Line at 50 CFU/100mL signifies the measurements with values <100 CFU/100mL, except for household #28, which had a measured value of 50 CFU/100mL

Figure 37 indicates that while 7 of the 59 households indicated the presence of EC in the filtered only water, only one household (#31) had EC contamination in their filtered and chlorine disinfected water.

Table 25: Number of Households with No Bacterial Contamination (<100 CFU/100mL) at Time of Baseline Survey and Follow-up Survey

Community	Households with No TC		Households with No EC	
	Baseline	Post-Intervention	Baseline	Post-Intervention
Kalariga	5/24=21%	12/24=50%	21/24=88%	24/24=100%
Kakpagyili	21/35=60%	26/35=74%	31/35=89%	34/35=97%
Both	26/59=44%	38/59=64%	52/59=88%	58/59=98%

This data is significant because many households that had a low microbial contamination during the baseline survey did not indicate bacterial presence during the follow-up survey. In many ways, this data is more representative than averaged microbial concentrations. This is because with averaged data, households with minor (yet significant) reductions are not as highly represented. For example, during the follow-up survey only one household showed the presence of EC. However, because this one household had a high EC count, the average EC count after using Aquatabs of all the households surveyed actually increased. Furthermore, in Figure 35 household #11 had an increase in TC count from 11,100 CFU/100mL to 42,000 CFU/100mL. This increase is significant; however, it is much more significant when it is averaged among TC counts from other households on the order of 50-5,000 CFU/100mL.

Table 26: Averaged Bacterial Indicator Test Results

	TC (CFU/100mL)				EC (CFU/100mL)	
Community	Filtered-only	Filtered+ Aquatabs	% Reduction	Log Removal	Filtered-only	Filtered+ Aquatabs
Kalariga	2,200	2,039	7	0.04	61	50
Kakpagyili	2,900	874	70	0.52	60	110
Total	2,635	1,328	50	0.30	60	86

Table 26 represents an average baseline (filtered) and post-intervention (Filtered+Aquatabs) TC concentration among all of the households in Kalariga, Kakpagyili, and the total of both communities.

Table 27: Median TC Test Results During Baseline and Post-Intervention

	TC (CFU/100mL)	
Community	Filtered-only	Filtered+Aquatabs
Kalariga	500	<100
Kakpagyili	<100	<100
Total	200	<100

The median TC value in Kalariga for the filtered only water was 500 CFU/100mL, whereas the median TC value in Kakpagyili was <100 CFU/100mL. Furthermore, the median TC of all of the samples taken was 200 CFU/100mL for the filtered only water, and the median TC concentration for both communities, and the two combined, for the filtered and chlorine disinfected water was <100 CFU/100mL.

3.4.3 Chlorine Residual Test Results

As discussed previously in *1.4.2 Aquatab Tablet Weight and Dosing Requirements*, the FAC level should be no less than 0.2 mg/L 24 hours after Aquatabs have been added to water. During the follow-up survey, respondents were asked when they last dosed their water. Because the follow-up survey was conducted seven days after the baseline survey, households had added Aquatabs to their water source anywhere from 0-5 days previously (because data shows that at least two days are required to obtain the full 20 L of water needed for dosing with Aquatabs).

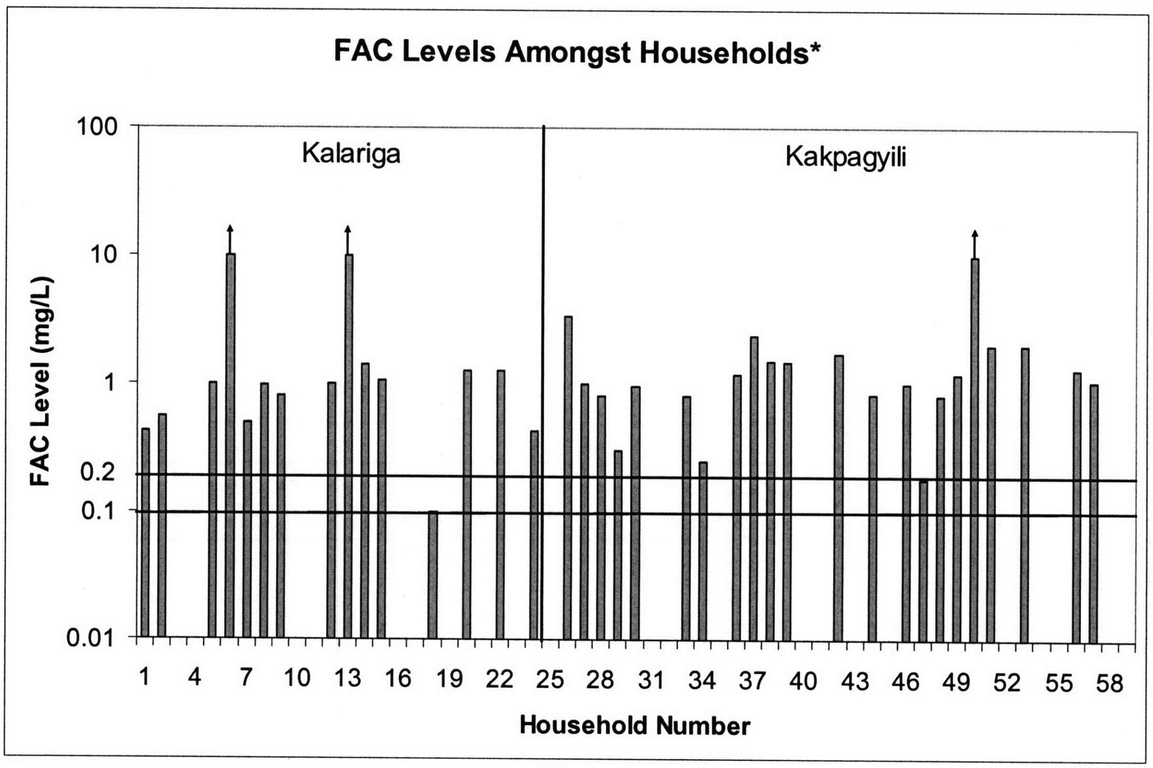


Figure 38: FAC levels among households surveyed in log-scale.

*Lines at 0.1 and 0.2 mg/L represent the CDC benchmark for FAC from random samples and the CDC minimum for FAC residual 24 hours after dosing, respectively

Figure 38 shows the FAC levels of all of the households surveyed. The three values of 10 mg/L actually represent FAC levels that were ">10 mg/L", but were plotted at 10 mg/L for scaling purposes. When the FAC was greater than 10 mg/L, the value was noted as >10 mg/L, and the testing was stopped (this was done to conserve the supply of reagents used to conduct the FAC test). Additionally, 22 of the 59 households (37%) had a FAC level of 0 mg/L at the time of the follow-up survey. Furthermore, 28 of the 59 households (40%) had a FAC residual below the CDC recommended 0.2 mg/L value 24 hours after testing; however, for many of these households, it is unclear when the households last dosed their water, so many of these water samples may have been dosed more than 24 hours previously.

In Liz Blanton's CDC study, the FAC was reported as the percentage of samples taken that were greater than 0.1 mg/L, essentially indicating a cutoff between chlorine residual detection and non-detection. In her results the percentage of samples greater than 0.1 mg/L ranged from 50-85% (Blanton, 2006). However, it should be noted that Blanton's research was conducted in a community where over 90% of households had access to piped water supply. As a result, among the households with piped water supply, the water presumably already had a FAC residual prior to the addition of Aquatabs.

Table 28: Percent of Households with a FAC Residual >0.1mg/L at Time of Visit

Community	Households with FAC >0.1mg/L at Time of Visit
Kalariga	15/24=63%
Kakpagyili	23/35=66%
Both	38/59=64%

Table 28 shows that the percentage of households in this study with a FAC residual greater than 0.1 mg/L at the time of the visit was within the range from Blanton's study.

To better understand the relationship between FAC levels—particularly in households with 0 mg/L of FAC—and the number of days that had elapsed since dosing, many of the households in Kakpagyili were asked when the water had been dosed with Aquatabs.

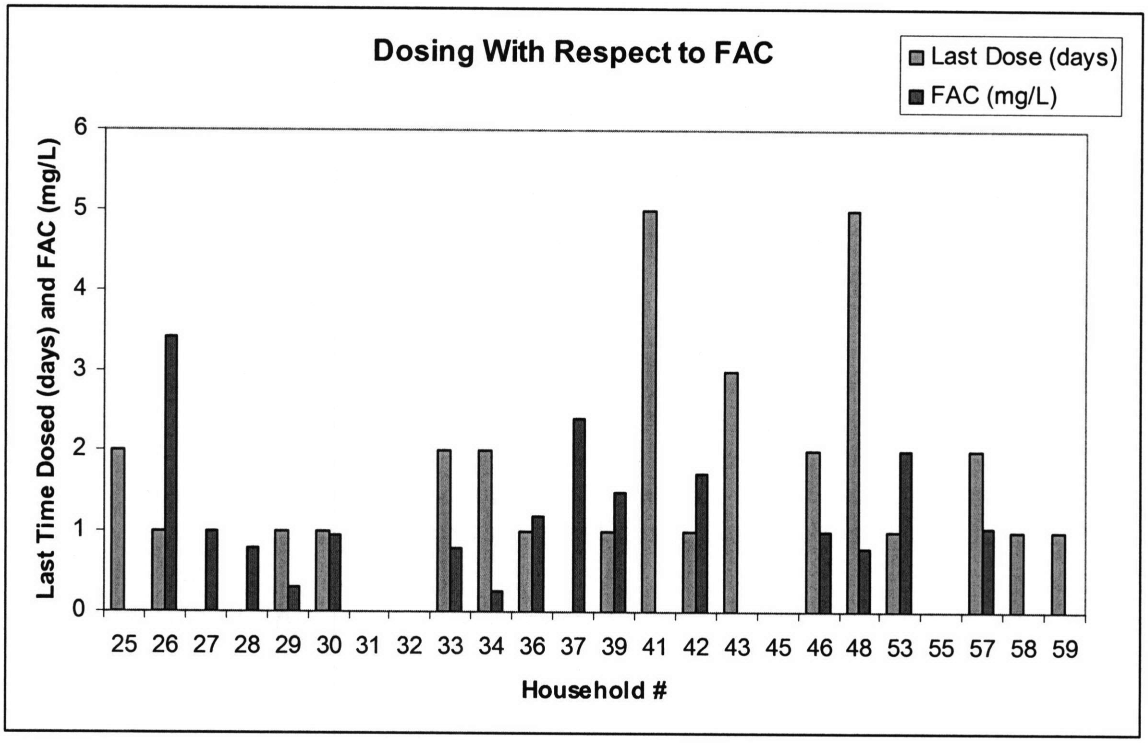


Figure 39: Comparison of FAC levels with time from last dose.

In Figure 39, the households that have 0 days from the last dose and a FAC level of 0 mg/L represent households that dosed the same day as the survey and have no FAC in their water source. Likewise, household #26 dosed the day before the survey and had a FAC level of 3.4 mg/L.

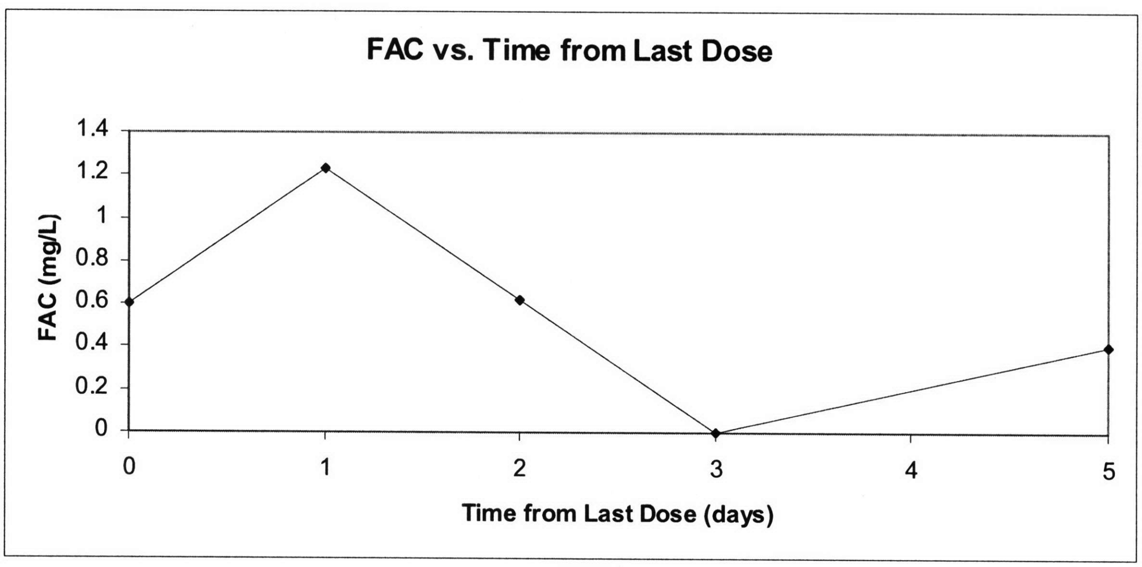


Figure 40: Averaged comparison of FAC levels with time from last dose.

From Figure 40, households that had dosed 0, 1, 2 or 5 days before the follow-up visit had a FAC residual in the proper range. This is based upon 7, 9, 5, 1 and 2 samples (24 total) for the 0, 1, 2, 3 and 5 days elapsed time periods, respectively.

To summarize how the FAC residual affected the microbial contamination in the post-intervention samples, the following two plots show the percentage of households with decreasing and increasing TC concentrations (for various FAC ranges). The "n=x/y" values on the x-axes indicate the number of samples with either a reduced or increased TC concentration (x) out of the total number of samples with that specific FAC range (y). The percentages from the two graphs do not sum to 100% because many of the household's TC concentrations remained the same from baseline to follow-up.

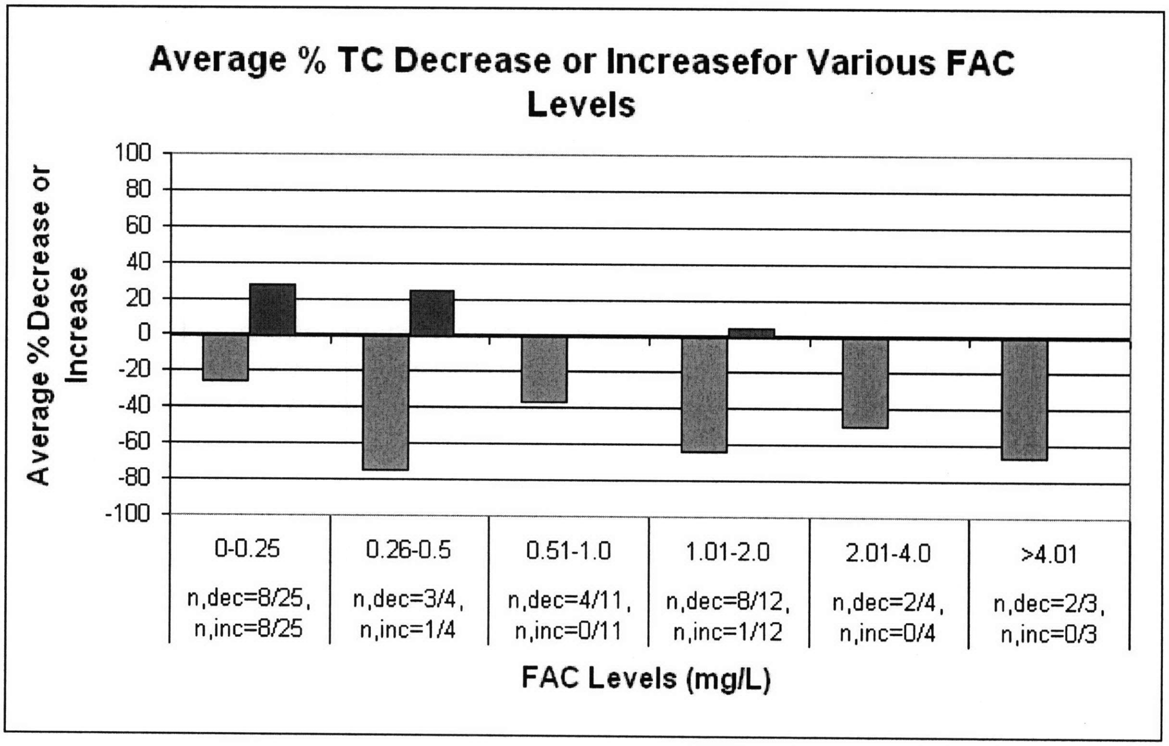


Figure 41: Percent of households that had reduced and increased TC concentrations at post-intervention for different FAC ranges.

In terms of EC reduction, of the seven households that indicated the presence of EC in the filtered-only samples but did not after using Aquatabs, the FAC levels were 0.5, 0, 0, 0.8, 2.4, 0, and 1.05 mg/L. This is an average FAC level of 0.68 mg/L, which is only 3% higher than the average FAC level of 0.66 mg/L (average without three samples >10mg/L) from all of the samples taken. On the other hand, the only household that had an increased EC concentration had a FAC level of 0 mg/L.

3.5 Laboratory Tests

Over the course of the three weeks spent in Tamale, laboratory tests were performed to determine the treatment effectiveness of the combined *Kosim* and Aquatabs system and to assess the flow rate through the ceramic filter using local water sources. Two important variables affecting flow rate are water quality and prolonged use. Therefore, in order to better understand the flow rate, the following five flow rate tests should be performed:

1. New filter, water of high turbidity and microbial contamination
2. New filter, water of high turbidity and low microbial contamination
3. New filter, water of low turbidity and high microbial contamination
4. New filter, water of no turbidity and no microbial contamination—"clear water"
5. One year old filter, water of high turbidity and microbial contamination

Flow rate tests 1-4 determine to what extent turbidity and microbial contamination have on flow rate. However, because of time restrictions while in Ghana, only flow tests 1 and 3 were performed. The dugout water closest to the lodging site (Dugout1-Taha) and the second closest dugout to the lodging site (Dugout2-Ghanasco) were tested on new filters for flow rate test #1. Vended tanker truck water (Tanker Truck) was tested on a new filter for flow rate test #3. Water from the two dugouts was collected in jerry cans on a bicycle. The vended tanker truck water was available at the household where the author's laboratory was set up.

It is also important to understand the relationship of flow rate with prolonged use. During filtration, particles and microbes become embedded in the ceramic filter over time, impeding the flow of water through the filter. Test #5 was performed with dugout water from the Kalariga Dam, the same dam that is used by one of the two interviewed communities.

When the author returned to the US, he was able to acquire three new *Kosim* filters. With these filters, which were different units than the new filters tested in Ghana, he was able to perform flow test #4.

For each flow rate test performed, the filter was thoroughly scrubbed with a brush and rinsed prior to testing. Afterwards, each filter was filled to the top of the ceramic pot and allowed to filter the full contents of the put, without topping off. Throughout testing, the filtered water level was marked on the plastic storage receptacle at various time intervals. The markings were then measured with a 100 mL graduated cylinder to determine the volume of water filtered between markings. The data was then used to create accumulated flow versus time charts.

3.5.1 Flow Rate Tests on New Kosim Filters with Dirty Water in Ghana

While in Ghana, three new *Kosim* filters were set-up, one for each of the three Dugout1-Taha, Dugout2-Ghanasco, and Tanker Truck water sources. The turbidity values for the three water sources were 200 NU, 300 NU, and <5 NU, for Dugout1, Dugout2-Ghanasco, and Tanker Truck waters respectively.

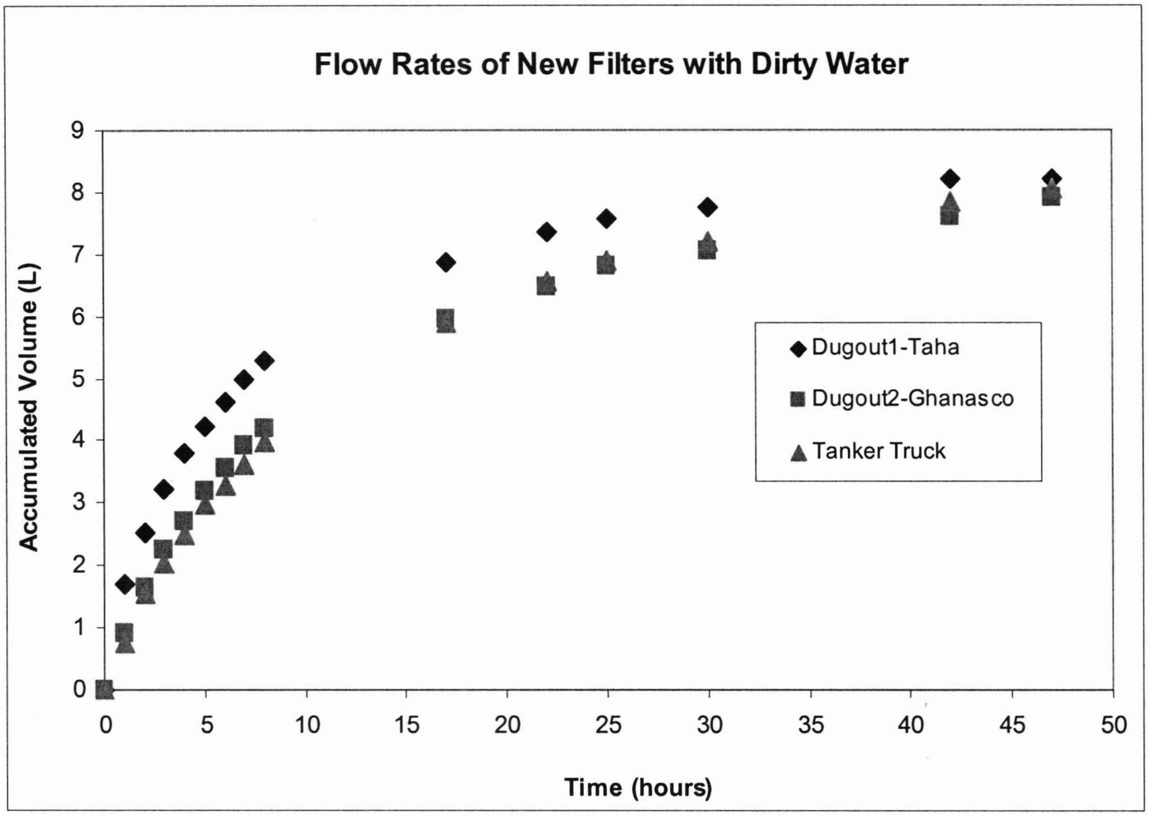


Figure 42: Accumulated flow over time for three new Kosim filters with dirty water. The square diamonds represent dugout water (200 TU), the pink squares represent different dugout water (300 TU), and the green triangles represent clear, tanker truck water (<5 TU).

Over the first hour, the flow rate through the Kosim filters was 1.7 L, 0.9 L, and 0.8 L for Dugout1-Taha, Dugout2-Ghanasco, and Tanker Truck respectively. During the second hour, the amount of flow was reduced to 0.8 L, 0.7L, and 0.8L, and during the third hour, the flow was further reduced to 0.7 L, 0.6L, and 0.5L respectively. This exponential reduction in flow rate over time is displayed in Figure 40. The water from Dugout1-Taha required 42 hours to completely filter through the *Kosim* filter, whereas the water from both Dugout2-Ghanasco and Tanker Truck required 47 hours to completely filter. The filtered water was also tested for turbidity, TC, and EC, which will be presented in the following section. Essentially all three filters took approximately two days to completely filter one full ceramic pot of 8.1 L when no additional water was added to "top up" the ceramic filtering element.

One shortcoming of this test, realized after obtaining the results and discovering that the flow rate of the Tanker Truck was slower than the dugout water filters, is that a "clean water" trial (see Section *3.5.3 Flow Rate Test on New Kosim Filters with Clean Water in US*) was not run at the outset to determine a baseline flow in all three filters.

3.5.2 Water Quality Tests on Performance of Combined System

Once all of the water had filtered through the new respective *Kosim* filters, additional water was continually added to each filter, until 20 L of filtered water was available from each of the three water sources. At that point, each of the three water samples were emptied into 20 L jerry cans and dosed with Aquatabs. After 30 minutes, this water was tested for turbidity, TC, EC, and FAC.

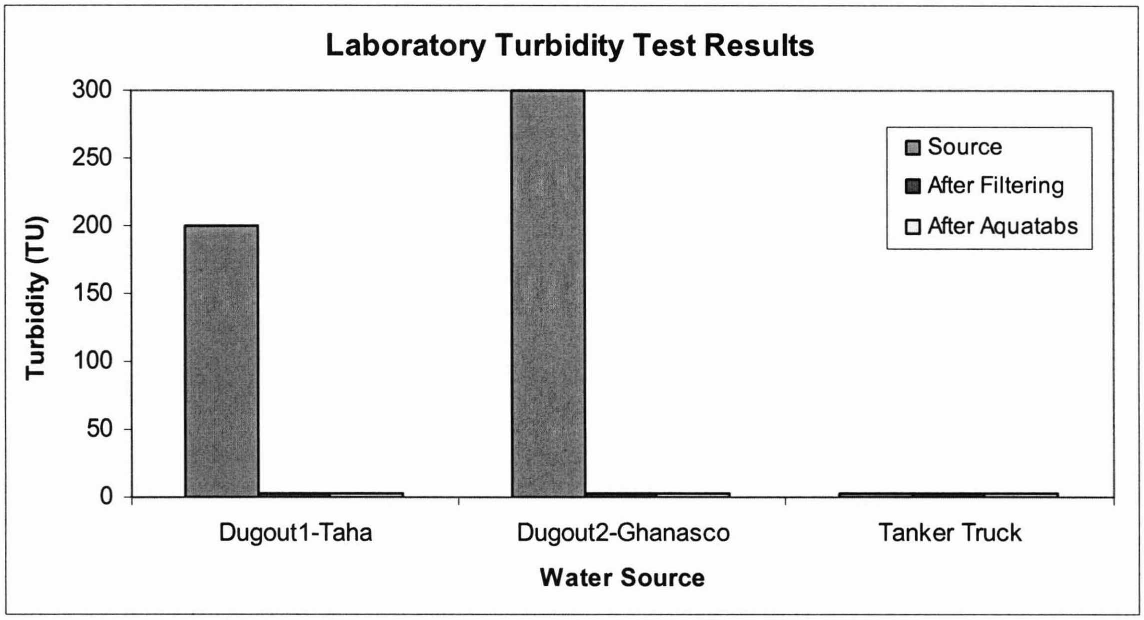


Figure 43: Turbidity test results for different stages of treatment in field laboratory.

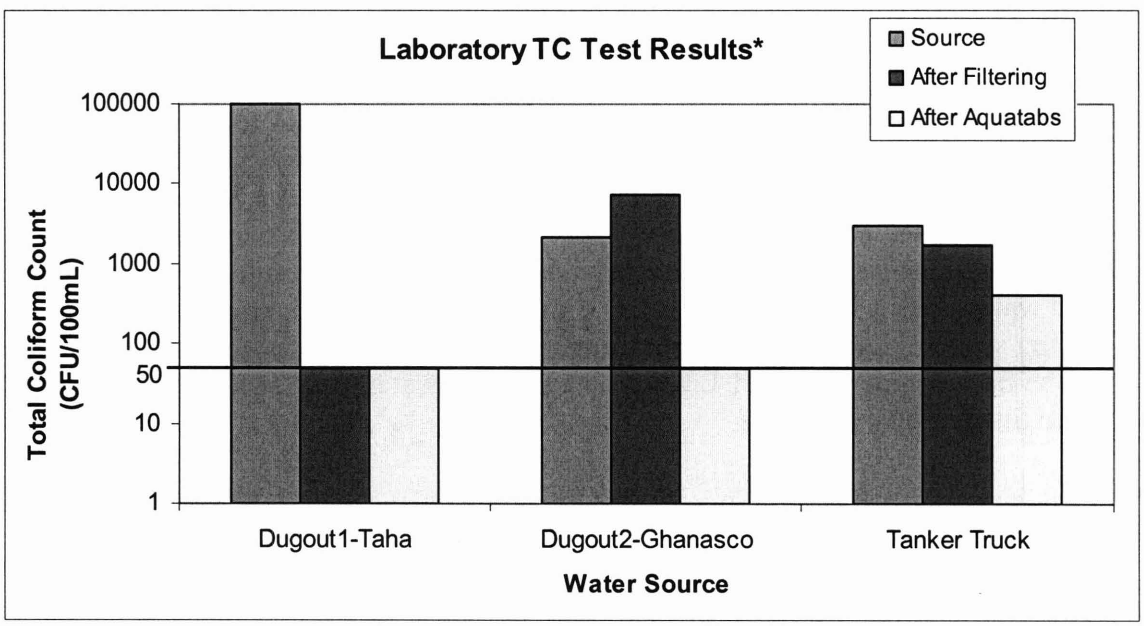


Figure 44: TC test results for different stages of treatment in field laboratory (log-scale).

*Line at 50 CFU/100mL signifies the measurements with values <100 CFU/100mL

Of the three different water sources, the only water sample that indicated the presence of TC after chlorine disinfection was the Tanker Truck source. Furthermore, none of the water sources indicated the presence of EC at any point in the testing process. In the Dugout1-Taha water, the turbidity and EC were reduced below detection during the filtration process. In the Dugout2-Ghanasco water, the turbidity was reduced below detection during the filtering, but not the TC. However, the presence of TC was removed after dosing the filtered water with Aquatabs. In the Tanker Truck water, the presence of turbidity was removed during filtering, and 43% of the TC was removed. After chlorinating, an additional 76% of the TC was removed, but interestingly, 400 CFU/100mL remained in the final water sample.

Table 29: FAC Residual for Laboratory Test Samples

Water Source	Dugout1-Taha	Dugout2-Ghanasco	Tanker Truck
FAC (mg/L)	0.97	1.15	0.69

Table 29 shows the FAC residual for these same three tests. All three results fall within an appropriate range, as prescribed by the CDC guidelines. The FAC tests were performed 30 minutes after dosing.

3.5.3 Flow Rate Test on New Kosim Filters with Clean Water in US

In order to perform flow test #4, three new *Kosim* filters were set-up in Medford, Massachusetts, where tap water was used for filtration (no turbidity, assumed to have no microbial contamination). This test was performed as a baseline case for flow rate through the *Kosim* filter (i.e. how does water filter when it is clear) in order to compare dirty water flow rates with clear water flow rates.

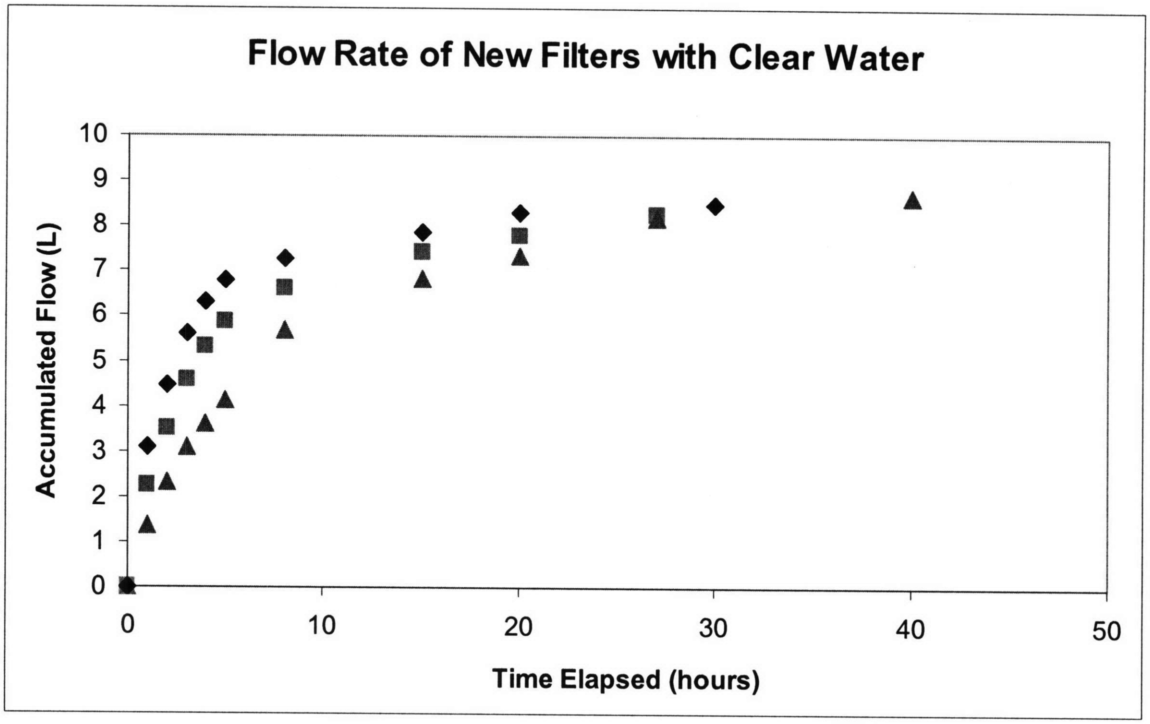


Figure 45: Accumulated flow over time for three new *Kosim* filters with clear water.

Over the first hour, the flow rate through the *Kosim* filters was 3.1 L, 2.25 L, and 1.36 L for the three samples. This represents an average flow of 2.24 L/hr for the first hour, which is nearly double the averaged flow rate of the dirty water samples tested with new filters (1.13 L/hr). Furthermore, it took 27, 30 and 40 hours to completely filter the clear water samples, whereas it took 42 and 47 hours to completely filter the dirty water samples, respectively. Also, it took 42 hours to filter the Tanker Truck water, which had no turbidity and high microbial contamination.

3.5.4 Flow Rate Test on Old Kosim Filter

In order to better understand how use affects the flow rate through the *Kosim* filter, a new ceramic filter was exchanged with an old filter from a household in Kalariga. During the baseline survey, the household that the filter was exchanged with complained about how slow the filter was. From PHW records, this filter had been in use for one year and was treating dugout water as its source supply. Water was gathered in 20 L jerry cans from the Kalariga dugout (Dugout3-Kalariga, the same source as was used by the woman from whom the filter was exchanged) in order to simulate the household filtering conditions as accurately as possible. The flow rate was tested in the same fashion as the three, new *Kosim* flow rate tests.

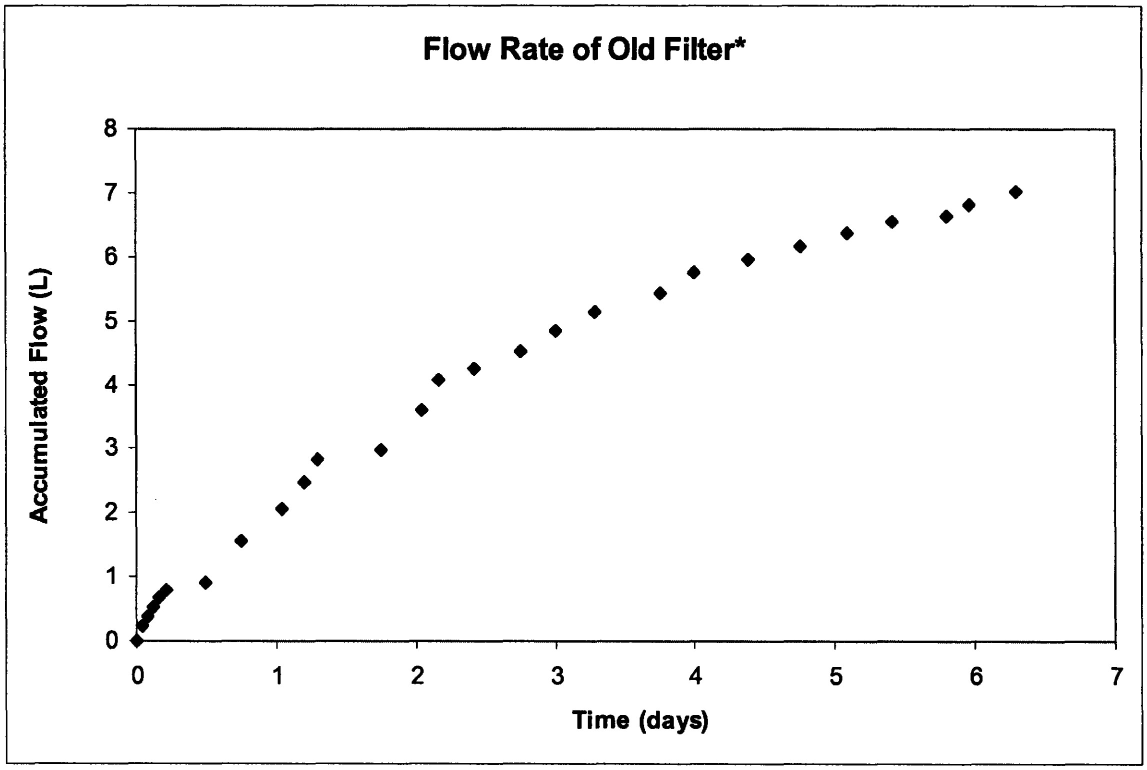


Figure 46: Flow rate of one year old filter.

*1.188 L remained in ceramic pot at end of test

It required 151 hours (6.3 days) to filter 7 L through this old *Kosim* filter. In comparison, it required 42 or 47 hours to filter the full contents (roughly 8.1 L) of water of similar turbidity and microbial contamination through a new *Kosim* filter. As noted, there was 1.188 L remaining in the ceramic portion of the filter at the conclusion of the test. This test had to be stopped due to time restrictions in Ghana, which is why only 7 L of water was filtered.

3.5.5 Comparison of Flow Rates

Because the two dirty water sample flows through new *Kosim* filters display similar behavior, the hourly flows from these two tests (Dugout1-Taha and Dugout2-Ghanasco) were averaged for comparison with the flow rate of other water sources. Likewise, the three clear water sample flows through new *Kosim* filters were similarly averaged. Table 30 shows these results.

Table 30: Hourly Flows (Liters) Through *Kosim* Filters for First 5 Hours of Filtration

Filter Age	New	New	New	1 Year Old
Water Quality	Clear, No Contamination	Clear, Contaminated	Turbid, Contaminated	Turbid, Contaminated
Number of Filters Tested	3	1	2	1
1st hour	2.24	0.76	1.32	0.23
2nd hour	1.19	0.80	0.77	0.16
3rd hour	1.00	0.48	0.65	0.15
4th hour	0.64	0.44	0.53	0.14
5th hour	0.51	0.49	0.46	0.13

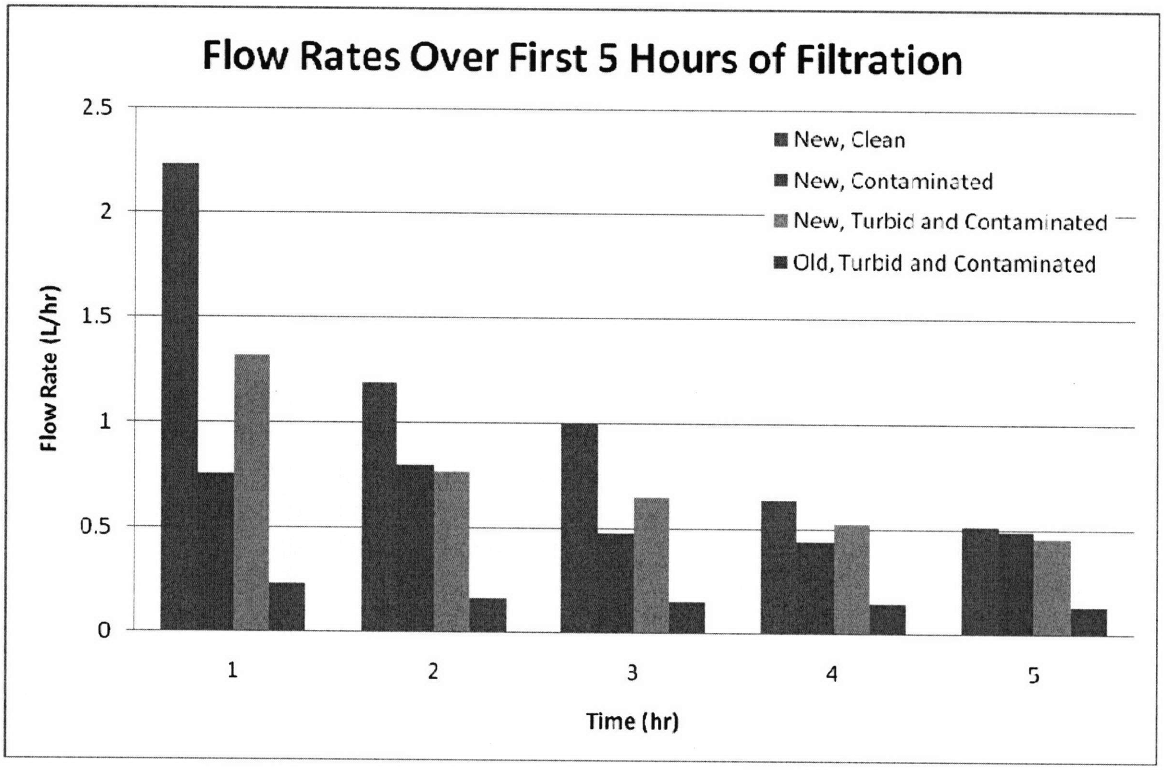


Figure 47: Flow rates over the first 5 hours of filtration time for different water sources and filters of varying age.

For further comparison, all three of the dirty water samples with new *Kosim* filters were averaged into one. Even though the Tanker Truck water was not dirty with respect to turbidity, it was microbially contaminated. This averaging was done because the flow behavior of all three of these samples was similar. This new set of values, the averaged clear water samples with new *Kosim* filters, and the dirty water sample with the old *Kosim* filter are plotted in one figure (Figure 48).

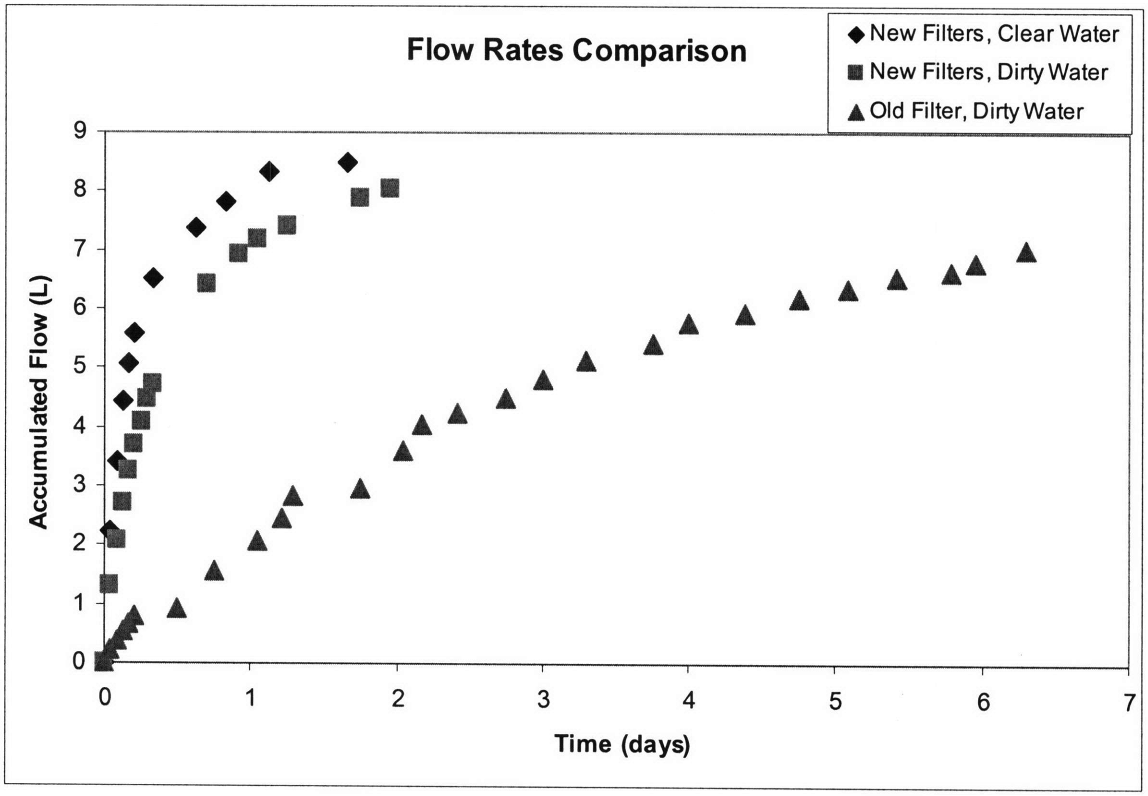


Figure 48: Flow rates of new filters with clear water, new filters with dirty water, and a one year old filer with dirty water (Dugout3-Kalariga).

4.0 Discussion of Results

4.1 Survey Results

4.1.1 Survey Biases

The following is a list of factors that potentially resulted in survey biases concerning the baseline and follow-up surveys conducted in this study (Fowler, 1993):

1. Not enough emphasis with respect to the instructions the survey respondents received
2. Interpersonal issues concerning demographic characteristics of interviewer
3. Problems associated with the free distribution of products
4. Inappropriate training of interviewers
5. Differences in stimuli concerning questions asked
6. Interviewers asking questions too fast
7. Use of "open" questions
8. Failure of use of "subjective continuum scale"
9. Poorly defined terms
10. Not enough sensitivity to questions with relation to social desirability
11. No data validation

These survey biases fall into two areas, the implementation of the survey (1-6) and the survey instrument (7-11). The following section elaborates on these potential survey biases in a sequential manner.

Concerning the survey instrument, one of the main shortcomings of this survey was that survey respondents were not properly instructed on how to respond to the survey questions. Floyd Fowler's book entitled "Survey Research Methods" stresses the importance of informing the respondents precisely what is going to happen and what is expected of them during the introduction of the study (1993). In this study, during the introduction of the baseline survey, households were told about the purpose of the study, but were not fully and properly educated on every aspect. The survey respondents should have been informed from the outset that a study about the combined use of the *Kosim* filter and Aquatabs was going to be conducted, that this would require a series of questions at two distinct times, and that households would need to use the combined system in the week between baseline and follow-up visits. That way, survey respondents would know exactly what to expect from the duration of the study.

Moreover, the survey respondents should have been further educated about the type of responses requested and the importance of honestly answering the questions. For example, the survey respondents should be told that some questions require the opinion of the household in their own words, while for others; a series of possible answers will be given from which the survey respondent can choose (Fowler, 2003). By introducing the survey this way, the respondents would be better prepared to answer the questions asked.

And some of the overwhelmingly positive answers might have been avoided to questions such as, "Would you recommend the use of Aquatabs to others?"

Because Ghana is a peaceful, English-speaking, politically stable country, which also has numerous needs with respect to disease, sanitation, water quality, etc. a large number of non-government organizations (NGOs), typically of Western origin, work in this area of the world. As a result, Ghanians—particularly in Tamale—are accustomed to interacting with white people. However, these interactions potentially create a relationship in which the Ghanian community members defer to the white volunteers, and automatically accept their advice or instructions as truth.

Therefore, an area of bias in the survey results is due to the fact that Ghanians generally give answers that they think the surveyor wants to hear, especially if that surveyor is white. This bias relates to interpersonal relations, when someone brings obvious demographic characteristics into an interview. According to a number of Ghanian natives, people in Ghana generally think that white people are always correct. This mentality might be due to the fact that Ghanians perceive Westerners as better educated than Africans.

While not proven scientifically, it is thought by the author that this issue is further perpetuated when non-government organizations provide help for free. In the case of Kalariga, the *Kosim* filters being used by this community were given for free (see Section *2.2.1 Community Selection Strategy*). While the community members are grateful for this gift, they also have come to expect further acts of gratitude from people outside of their community. This expectation was verified on the first day working in Kalariga, when the village volunteer inquired, "How many filters do you want to give me?" While the community members cannot be faulted for this mentality, it is important to consider this when observing the survey results from this community. Because these community members have been given gifts, they are going to be even more inclined to provide answers that they think will please people from outside their community—particularly concerning their free *Kosim* filters—in the hope that they will receive more gifts. If these same people had paid for their filters, as was partially the case in Kakpagyili (where payments on credit were underway over the previous three months in Ghana), then they might feel more entitled to complain about the functionality, durability, effectiveness, etc. Additionally, now that there was an expectation in Kalariga that more gifts might be provided in the future, the community participants have an incentive to give answers that will help to further foster a mutually-beneficial relationship.

While this dynamic is theoretically less prominent in Kakpagyili—where filters were purchased—community members still may have a tendency to provide answers that they think the surveyor wants to hear. This has to do with the interpersonal relations of the surveyor and the respondents, with respect to the natural tendency of Ghanians to defer to Westerners. It is also a potential confounding factor in the follow-up survey. For the purpose of this study, the Aquatabs were provided for free. This was done to ensure uniform participation within the communities. But because the Aquatabs were given for free, the community members likely felt an obligation to respond positively to any questions pertaining to the product. This would equally apply to Kalariga as well as to Kakpagyili.

The responses given during the follow-up survey support this theory. When asked, "Are the Aquatabs easy to use?" and "Would you recommend the use of Aquatabs to others?" all 59 households said "yes" to both questions. Furthermore, when asked, "Have you had any problems using the Aquatabs?" all 59 households replied "no". These answers are overwhelmingly positive, however, after further discussing the use of Aquatabs with certain households, it became apparent that they were not as universally pleased with the product as the survey results indicate. As mentioned in Section *3.2.2 Filter and Aquatabs Perception Survey Results*, three households (two in Kalariga, one in Kakpagyili) indicated that they had experienced specific problems associated with the Aquatabs. This suggests that the survey respondents were not entirely forthright with their responses, and were likely giving the answers that they assumed the surveyor wanted to hear.

Another area of survey bias has to do with the quality of the interviewers. Fowler stresses the importance of properly training the interviewers when conducting surveys, reporting that survey precision can be reduced by 20-30% as a result of poor interview staff (Fowler, 1993). In this case, surveyors were needed to translate questions from English to Dagbani. As previously mentioned, four Ghanians assisted with the survey implementation: Zach, Chairman, Napps and Tuu-Naa. While conducting the baseline and the follow-up surveys, each of these people performed the translation at various times. Despite the fact that the author was present for each of the interviews, the language barrier prevented the author from discerning the quality of the translated questions. Moreover, while Napps was educated about the purpose of the study and about the significance of particular questions, the other surveyors were not as well-informed. Therefore, this discrepancy likely led to biases in responses to particular questions.

Furthermore, as a result of using different surveyors, the questions were likely not asked the same way each time. Some of the translators may have been more persistent in obtaining responses to certain questions. For example, when inquiring how much the community members would be willing to pay for 100 Aquatabs, there may have been a difference in how the different translators approached that question. Some may have been more insistent about the community members paying the full GHC 3, while others may have been less forceful with their inquiries. Lastly, the speed with which questions were asked varied among the different interviewers. It was obvious to the author that some translators were patient regarding responses, while others were not. This would greatly affect the quality of the results, as complete responses may not have been given during rushed surveys. With the language barrier, it is impossible for the author to know how much of a factor the use of different translators had on the survey results.

There were also a number of biases associated with the survey instrument. One issue is that many questions that should have been "closed" questions (questions with a list of possible replies) were inappropriately framed as "open" questions (questions where the respondent answers the question in their own words). This could have been applied to questions regarding water sources, treatment methods, etc., which might have resulted in more accurate results. When a respondent is responding to an open question, they tend to only provide one answer, when in reality, a number of answers could be provided. This limits the quality of the results.

Another area where bias may have been introduced was by not using a "subjective continuum scale", where a range of possible responses are given for the respondent to choose from. For example, when asking how someone feels about something, a more descriptive response is often received if the respondent has a list to choose from (e.g. excellent, very good, good, fair, poor) (Fowler, 1993). By not employing this strategy, but rather asking respondents questions such as "Did the Aquatabs improve the taste of the water?" the thoroughness of the response was limited.

The poorly defined terms and social desirability biases are relevant because of how they relate to the diarrheal history of the households. Bias from poorly defined terms relates to how respondents view questions differently. Social desirability relates to questions which the respondent may not want to report accurately because they may feel embarrassed or ashamed as a result of the social culture they live in. By not correcting for these two factors, the survey results with respect to diarrheal history may have been biased. These biases will be discussed in further detail in later sections.

Lastly, the survey results from this study were not validated. In standard practice, a question is asked that the interviewer is able to verify. For example, by first asking, "Are you using the *Kosim* filter?" and then observing if there is water in the upper and lower levels of the *Kosim* filter. Upon verification that the survey results are true to documented evidence, the data set is considered verified. Because this was not done, it is unclear whether the results gathered from the two surveys are entirely accurate.

Suggestions on how to improve the surveys used in this research study are included in the Section *7.1.2 Improvements to Survey Process*.

4.1.2 Baseline Survey Results

In response to Question 5 from the baseline survey ("Do you ever drink unfiltered water?"), only 7 of the 59 respondents indicated that they drink unfiltered water. However, on average these same households fill their filters only 2.9 times per week. From the seven flow rate tests performed on *Kosim* filters, a full ceramic filter provides a volume of 8-8.5 L of filtered water. Using a ceramic filter volume of 8.1 L, and only filling the Kosim filter 2.9 times per week, the average household filters 23.5 L of water per week, or 3.4 L per day. Additionally, most households only have one filter per household, which is typically composed of about 12-14 people, as discussed previously.

These numbers suggest that each person only has access to 0.3 L of filtered water per day. With hot and dry climatic conditions in Northern Ghana, it is expected that the average individual would require more than 0.3 L of water per day. The WHO suggests that the minimum necessary volume of water required per person per day is 7.5 L for consumption and food preparation (Howard and Bartram, 2004). Even though the households use other water for food preparation, there is reason to believe that more than 7 of the 59 households sometimes drink unfiltered water. The reason households may not be entirely truthful about drinking unfiltered water relates to the hypothesis described previously, that many of the survey respondents may be providing answers that they think want to be heard by the survey team, as a result of free distribution and interpersonal relations.

Question 1c ("How much water was in the receptacle?") was included as an observational question to determine if the households are actually using their *Kosim* filters. The average volume of water in Kalariga and Kakpagyili was 3.9 L and 10.1 L, respectively. This average difference could mean many things. It may mean that the people from Kalariga use their filters more frequently than the people from Kakpagyili. It could also pertain to differences in filter cleaning habits. Additionally, despite the fact that households in Kalariga had less water during the baseline, according to the survey results, they fill their filters more frequently than households in Kakpagyili (3.3 times per week, compared with 2.6 times per week). This might suggest that the filters in Kalariga are more clogged, as a result of use, and thus have a slower flow rate, which would explain why less water was available at baseline.

With respect to Question 4 ("When did you purchase your filter?"), the response in Kalariga was varied. An important thing to note is that many of the household respondents are uneducated, and thus their answers may not be precise. As mentioned earlier, only 13% of people in Northern Region, Ghana are literate (GSS, 2003). Further research by Green indicates that only 19% of people in Tamale area have completed primary education, while only 3% have completed secondary education (Green, 2008). When the survey respondents were asked how old they were, many laughed. It is possible that social desirability was a factor in the nature of their responses, but it is likely that the reason they laughed was because they did not know an approximate age. This creates some uncertainty with regards to the length of time that the survey respondents indicated they possessed their filters, with answers varying from eight months to two years. In reality, community members in Kalariga all received their filters one year prior to the household visits (Dia, 2008).

The fact that many of the rural community members are uneducated also creates some uncertainty regarding other questions about time and frequency. In particular, questions 7, 8, and 16, which relate to how many times per week the households fill their filters, the last time the filters were cleaned, and the last time that someone in the household had diarrhea, respectively.

When the survey respondents were asked, "When was the last time you cleaned the filter and storage unit?" 45 of the 59 households indicated that they had cleaned their filter within the previous three days. The average answer to this question was 2.8 days prior to the survey, which roughly equates to two times per week if the filters are cleaned once every three days. During distribution of new filters, households are instructed to clean the filters whenever the filtration rate drops. This is done to ensure that the filters do not get clogged, and are thus functioning with an optimal flow rate. Given that households fill their filters an average of 2.9 times per week, which is roughly the same frequency with which the filters are cleaned, it is reasonable to assume that the filters are cleaned each time that they are used. Furthermore, all 59 of the respondents were able to effectively demonstrate the cleaning of their ceramic filters and storage receptacles.

Concerning Question 13 from the baseline survey ("Is the filter easy to use?"), 8 of the 59 respondents (14%) answered "no" to this question. All 8 of those respondents indicated that the reason that it wasn't easy to use was because its flow rate was too slow. However, the survey respondents provided this information about the flow rate without being prompted. Thus, it is highly possible that the other community members felt similarly about the flow rate through the *Kosim* filter, but did not voice that because the question was not directly related to that aspect of the filters. This is a result of asking "open" questions rather than "closed" questions, as described previously.

A similar miscommunication may have occurred with respect to Question 15, which asks, "Before you got the *Kosim* filter, did you treat the water at all?" All 59 respondents indicated that they did previously treat their water; however, the method of treatment is unclear. All respondents indicated that they used the Guinea Worm Cloth Filters, while only 4 of the 59 households (7%) indicated that they used both the Guinea Worm Cloth Filters and aluminum sulfate (a.k.a. "alum", a common coagulant in Northern Ghana). Because the respondents were not asked specifically about alum, it is possible that many of the respondents may have only been referring to their cloth filters, even though they also used alum. This hypothesis is supported by the fact that 44% of 119 rural households surveyed in another study in the Northern sector of Ghana indicated that they used alum (Green, 2008).

A further subset of Question 15 is "Did that (the previous treatment method) work?" All of the respondents indicated that their previous treatment method worked. However, the question did not specify what was meant by the word "work". Most likely, the community members were referring to the ability of the cloth filters to remove the cyclops, which is the guinea worm vector. Understanding the question that way, everyone would agree that that treatment option "worked", because it effectively removed the cyclops from the source water. However, the objective of the question was to determine if the community members thought that their previous treatment technology was sufficient at treating their water. In short, the responses given cannot be used to answer that question because the question needed better framing.

Of particular interest to PHW, the *Kosim* filter distributors, is the difference in the breakages between the two communities. Kalariga experienced five breakages out of the 24 filters in the community (21%). These five breakages occurred over a one-year time period. On the other hand, in Kakpagyili, none of the households experienced breakages in the first three months. PFP suggests that the ceramic filters be replaced once every year (PFP, 2008), while PHW suggests that the ceramic filters be replaced once every three years (Jackson and Murcott, 2007). However, it is not just the ceramic portions of the filters that incurred breakages. In Kalariga, two receptacles and one lid cracked, and one tap broke (in addition to the one cracked ceramic filter). These breakages are supposed to be reported to the village volunteer, who then contacts the salesperson associated with that community liaison. However, many of these households had not yet contacted their volunteer, and the others had not yet received replacement parts for their broken filters. In Kalariga, this equates to a 21% breakage rate per year.

Finally, there is also some uncertainty concerning the diarrhea occurrence of the community members. Households were asked, "When was the last time someone in your house had diarrhea?" If the household could remember the last time someone had diarrhea, then the following question was asked, "How old was this person?" While 14 of the 59 households (24%) were able to remember the last time someone had diarrhea, it is possible that there may have been even more cases. This is due to the poorly defined terms in and the social desirability of the question, as described previously. The question does not specify a length of time. Therefore, some households may have thought the question was only pertaining to the previous few months, while others may have thought the question extended as far as they were born. Because a time span was not specified, the accuracy of the results is not certain.

Furthermore, there may be issues concerning the social desirability of this question. It is possible that the survey respondent simply didn't know if anyone had had diarrhea recently, or chose not to disclose that information. Without knowing the cultural norms of Ghanian society, it is impossible to know whether diarrhea is something that is discussed openly. As a result, it is possible that men of the household may not disclose diarrhea incidence with their wives and vice versa. It is also possible that mothers may be embarrassed about their children's diarrhea, feeling some responsibility for the sickness. If this was the case, then the mothers may have chosen not to discuss cases of diarrhea, and replied "no", even though someone may have had diarrhea recently.

4.1.3 Follow-up Survey Results

All respondents indicated that the Aquatabs "improved the taste of the water", in response to Question 3 from the follow-up survey. As discussed earlier in this chapter, it may be that the survey respondents were giving the answer that they thought the surveyor wanted to hear. However, an equally likely explanation is that the Aquatab-dosed water tastes more like "pure water" (discussed previously), which is also treated with chlorine, as was commented on by various respondents. Concerning the overwhelmingly positive answers given in response to Questions 4, 5, and 7 (which were about whether the Aquatabs were easy to use, if people had had any problems using the Aquatabs, and if they would recommend Aquatabs to others), it is likely that the survey respondents were trying to please the surveyor. As discussed previously, some of the same households that responded positively also complained about stomach aches, hernias and concentrated urine, and "not feeling well", as a result of using Aquatabs. This information suggests that some of the survey responses may not be reliable.

One large distinction between the two communities was in response to how much they were willing to spend for 100 Aquatabs. The two communities chosen were selected because one represented the lower-class (Kalariga), and the other represented the lower middle-class (Kakpagyili). While there was little difference in how the two communities perceived the Aquatabs, the amount that they were willing to pay was distinctive. The average price that people in Kalariga were willing to pay was GHC 1.8 for 100 Aquatabs, while the average price that people in Kakpagyili were willing to pay was GHC 2.9. Moreover, only 6 of the 24 households in Kalariga were willing to pay the full GHC 3 for 100 Aquatabs, whereas 33 of the 35 households in Kakpagyili were willing.

This distinction may be due to the fact that people in Kalariga were given their *Kosim* filters for free and so they expected their Aqutatabs for free as well. Another result of the free distribution of *Kosim* filters is that people from Kalariga may not value water purification technologies the same as paying customers. However, it is equally as likely that the distinction in the two communities' willingness to pay has to do with the difference in wealth. If the Aquatabs were subsidized by a charitable organization, and they only cost GHC 2 for 100 Aquatabs, then 16 of the 24 households in Kalariga and 34 of the 35 households in Kakpagyili expressed that they would be willing to purchase them. And if the Aquatabs were only GHC 1 for 100 Aquatabs, then 21 of the 24 households in Kalariga and all of the households in Kakpagyili expressed that they would be willing to pay for them. However, these statistics are based upon households that had the opportunity to use Aquatabs for free. It is unclear if households that had never previously used Aquatabs would be willing to pay similar amounts.

4.2 Water Quality Results

4.2.1 Turbidity Results

The turbidity value for the Kalariga Dam (400 TU, performed during the dry season) is similar to values obtained from previous research. Johnson performed three turbidity tests on the Kalariga Dam during the dry season in 2007, and obtained values of 8.6, 225, and 244 NTU (Johnson, 2007). However, these three samples were from households, rather than directly from the dugout, which likely had higher turbidity. Foran performed a turbidity test on the Kalariga Dam during the rainy season in 2007, obtaining a value of >2,000 TU.

The first stage of the household water management and treatment process involves the gathering of water from the dugouts and storing it in ceramic vessels in the households. The tests done in this study and others indicate that there are significant reductions in turbidity from source to pre-treatment storage. In Kalariga, the turbidity decreased from 400 to 150 TU (63% reduction), and in Kakpagyili the turbidity decreased from 800 to 201 TU (75% reduction). This percent reduction is due to the gravity settling of particulates and to the use of alum in one of the two households in Kakpagyili. The household that used alum had a turbidity <5 TU (99% reduction), while the other household in Kakpagyili—that didn't use alum—had a turbidity of 400 TU (50% reduction).

Similar reductions have been seen in other studies. For example, MIT Master of Science (SM) student Kelly Doyle's research indicates that the turbidity of a water sample from the Libga Dam in Savelegu (a town north of Tamale) decreased from 47 TU to 21 TU (55% reduction) in one day (Doyle, 2007). The turbidity was further reduced to 18 TU the following day (14% reduction, 62% total reduction), 15 TU the day after that (17% reduction, 68% total reduction), and 6 TU four days later (60% reduction, 87% total reduction), as shown in Figure 49.

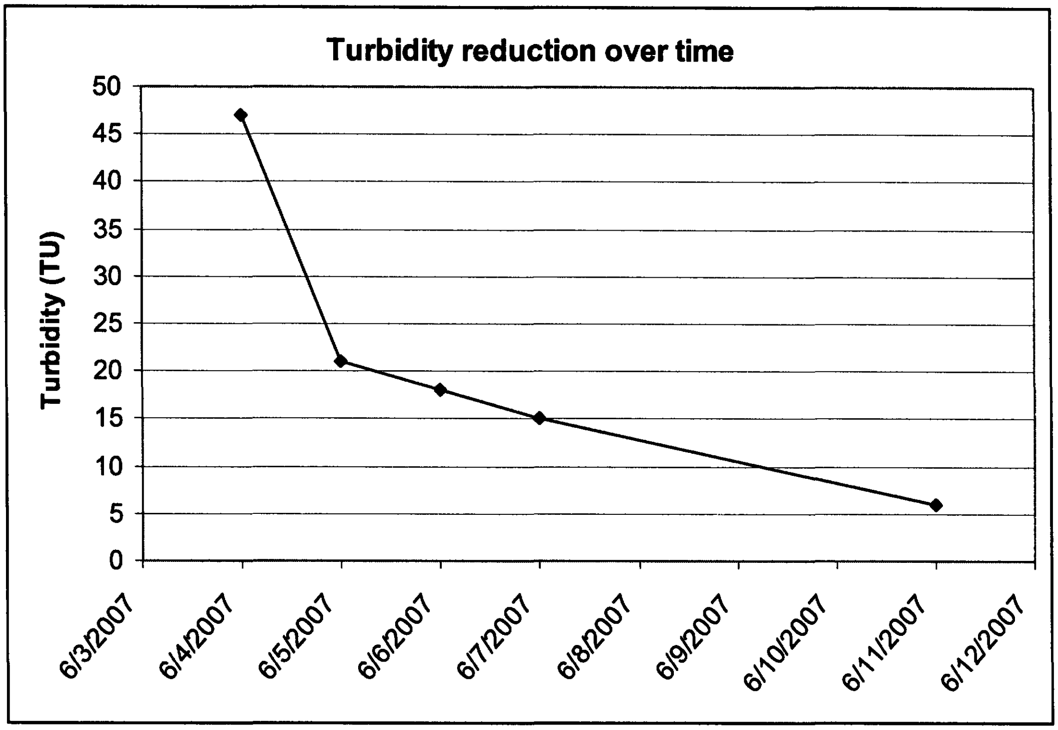


Figure 49: Turbidity reduction over time from water sample taken in Northern Region, Ghana (Doyle, 2007).

While the dugout water sample of Doyle's study was not as turbid at the source as any of the three dugouts in Kalariga and Kakpagyili, similar percent reductions can be expected from the water stored in the ceramic vessels. Another research study, performed by fellow MEng student Tamar Losleben, showed similar percent reductions.

Table 31: Reductions in Turbidity of Dugouts in Northern Region, Ghana by Gravity Settling (Losleben, 2008)

	Time Elapsed					
	0 Hours	24 Hours		50 Hours		
Dugout	Turbidity (NTU)	Turbidity (NTU)	% Reduction	Turbidity (NTU)	% Reduction	Total % Reduction
Gbrumani	48.2	11.6	76	7.94	32	84
Kunyevilla	124	19.5	84	9.82	50	92
Kpanvo	102	30	71	25	17	75
Ghanasco	201	132.5	34	120	9	40
Average	118.8	48.4	66	40.7	27	92

In this study, the average percent reduction in turbidity from the dugouts to the storage vessels was 72%. From Doyle's data, it would take four or five days to accomplish that amount of settling, whereas Losleben's data suggests it would take less than one day. It is possible that the water gathered from the dugouts is stored for as many as five days, if not more. It was observed by the author that most households have 2-5 ceramic vessels in their compounds for the sole purpose of storing water.

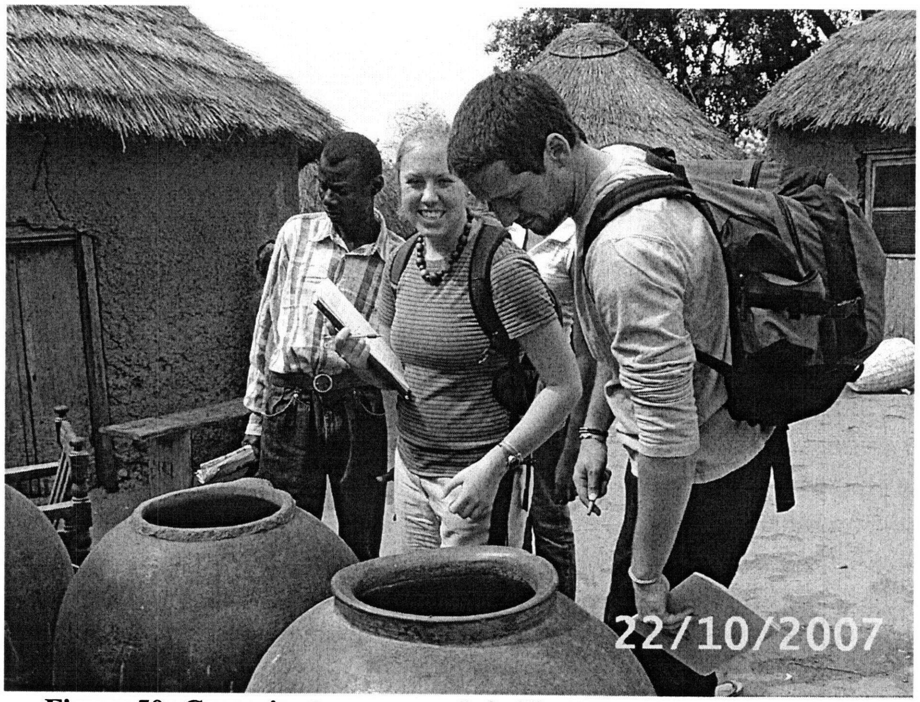


Figure 50: Ceramic storage vessels in Northern Ghana household.

When the households were visited in this study, the majority of the ceramic storage vessels were close to full. This suggests that the water used for filtering may very well have a storage period of four to five days prior to filtration.

The largest percent reduction among the four stages of water treatment (dugout, pre-treatment stored water, after filtering, after Aquatabs) occurs during the filtration through the *Kosim* filter. There were 89% and 92% reductions in Kalariga and Kakpagyili, respectively, and a total reduction of 91%. However, many of the filtered samples still had turbidity. Figure 33 and Figure 34 in Section *3.4.1 Turbidity Test Results*, shows the household-by-household turbidity results, which indicate that five filtered-only samples in both communities had turbidity values >5 TU, which ranged from 50-200 TU. The fact that the majority of the water samples were reduced below 5 TU suggests that those five households were doing something different than the others. Most likely, the households with 50-200 TU filtered-only water did not allow the dugout water time to settle in the pre-treatment storage vessels, prior to filtering. As described above and shown in Figure 49 and Table 31, a large amount of the suspended particulates can be removed by gravity settling. However, if this process does not occur, then water in the range of 400-1200 TU is added directly to the filter, which would likely make it more difficult for the *Kosim* filter to perform.

Another explanation is that the filters may be dysfunctional (e.g. cracks in the ceramic). However, that explanation is disproved by the filtered and chlorine disinfected turbidity results. If the five filters producing turbid water from the baseline were dysfunctional, then the same five filters should produce turbid water during the follow-up. However, this was not the case. In fact, not one of the five households produced turbid water during post-intervention. Instead, eight households that had clear water during the baseline had turbid water during post-intervention. This suggests that all of the filters are functioning properly, and that the most likely explanation for the turbid product water has to do with the amount of time the water is allowed to settle prior to filtration.

The average turbidity in Kalariga decreased from 17 TU to 11 TU (35% reduction) from the filtered-only water to the filtered and chlorine disinfected water.

In contrast, the average turbidity of the households increased (138%) from the filtered-only water (16 TU) to the filtered and chlorine disinfected water (38 TU) in Kakpagyili. In theory, the filtered only water would have no means of acquiring additional suspended particulates at any point between these two stages. The chlorine tablets would not interact with the suspended particulates, and so the turbidity should neither increase nor decrease as a result of the chlorination. The most likely explanation has to do with the fact that during the baseline the households were told that people would be returning in one week to test the water. As described in the previous section, according to the number of times that the households filled their filters per week, an average of 23.5 L of filtered water is available per week. Having experience using the filters, the households knew that they must fill their filters repeatedly in order to obtain the 20 L necessary for dosing, in order that they might have water available for testing during the return visit. Therefore, the households likely did not allow as much time for the dugout water to be stored in the storage vessels before filtering. Another explanation for this increase is natural variation. With a sample size of 59, it is possible that the turbidity increase was natural, and that if turbidity tests were performed again the turbidity may either further increase, increase to a less degree, or decrease when compared with the original results.

4.2.2 TC Test Results

The TC concentration for the Kalariga Dam source water is similar to values obtained in other studies. Johnson (2007) and Foran (2007) obtained TC concentrations of 43,000 CFU/100mL and 13,475 CFU/100mL, respectively. The value obtained in this study was 6,167 CFU/100mL, which falls in the range (4,000-69,000 CFU/100mL) of the four tests performed by Johnson (Johnson, 2007). However, this additional data suggests that the actual TC concentration of the Kalariga Dam may be even higher than the value presented in this study.

The TC concentration decreased through each stage of the treatment process, for both communities. From the dugout to the pre-treatment storage vessels, the TC decreased 19% in Kalariga and 65% in Kakpagyili. In Kalariga, this reduction is likely due to the cooler conditions in the ceramic storage vessels, when compared with the dugout

(Aimiuwua, 1993). The dugout in Kalariga is completely exposed to the sunlight, which increases the temperature in the water, creating a hospitable environment for bacterial growth. The water in the ceramic vessels is cooler, due to periods of shade and insulation from the ceramic. The cooler temperature inhibits bacterial growth, which may explain why the pre-treatment, storage vessels have lower bacterial contamination. Also, given that the TC concentration in the dugout may be even higher than the reported 6,167 CFU/100mL, there may be a larger percent decrease from the dugout to the pre-treatment storage vessels in Kalariga.

In Kakpagyili, the large TC reduction can be attributed partially to the use of alum. Of the two pre-treatment storage samples tested, the household that used alum had a TC concentration of 4,000 CFU/100mL, while the household that didn't use alum had a TC concentration of 8,000 CFU/100mL. The households were not asked which dugout they collected water from, so percent reductions for each individual household cannot be obtained (the two dugouts used by this community had varying TC concentrations, 11,000 CFU/100mL and 23,000 CFU/100mL).

The TC concentration was further decreased as a result of passing through the *Kosim* filter. Kalariga and Kakpagyili had reductions of 56% and 52% respectively, for an average decrease of 54%. In addition to having a higher percent decrease, Kalariga also had a lower TC concentration in the product water (2,220 CFU/100mL compared with 2,900 CFU/100mL in Kakpagyili). This fact is interesting because the filters in Kalariga were in use for four times longer than the filters from Kakpagyili (one year versus three months). This indicates that while the flow rates through the filters reduce with use, the ability to filter bacteria is not compromised and could, in fact, be improved. The average TC concentration in the filtered-only water from all 59 households in the study was 2,635 CFU/100mL.

The TC concentration for both communities was further reduced from the filtered-only water to the filtered and chlorine disinfected water. In Kalariga, the TC was reduced from 2,220 CFU/100mL to 2,039 CFU/100mL (7% reduction). In Kakpagyili, the TC was reduced from 2,900 CFU/100mL to 874 CFU/100mL (70% reduction). Neither of these reductions approaches the 100% reduction statistics released by Medentech, presented in Section *1.4.4 Performance* (Medentech, 2006). However, it is unlikely that Medentech was testing its product on such challenging water sources.

There are numerous reasons why the TC reductions were not as high as expected. For one, the 20 L jerry cans that were distributed with the Aquatabs may have been contaminated. For the purpose of this study, jerry cans were purchased from the local market. These jerry cans were formerly used to hold palm oil, which is used for cooking. Although they were washed thoroughly before distribution, it is possible that these jerry cans contained bacterial contamination before distribution.

Of the 59 households surveyed, 47 had used one Aquatab and 12 had used two Aquatabs in the week between visits. If there were bacteria present in the jerry cans distributed to the community members, then it would likely be diluted each time that water was dosed within the jerry can. Therefore, it is expected that the households that used two Aquatabs between baseline and post-intervention would have a greater reduction in TC concentration.

Table 32: TC Concentration Before and After Using Aquatabs Compared with Number of Aquatabs Used Between Baseline and Post-Intervention

Number of Aquatabs	TC Concentration Filtered-Only (CFU/100mL)	TC Concentration Filtered+Aquatabs (CFU/100mL)	% Decrease
1	2,260	1,250	45
2	4,104	1,633	60

For the households that only used one Aquatab, the average TC concentrations before and after using Aquatabs were 2,260 CFU/100mL and 1,250 CFU/100mL respectively, for both communities (45% reduction). For the households that used two Aquatabs, the average TC concentrations before and after using Aquatabs were 4,104 CFU/100mL and 1,633 CFU/100mL (60% reduction). The filtered and chlorine disinfected water from the households that used two Aquatabs had a higher average TC concentration. However, those households also had an average initial TC concentration that was nearly double that of the households that only used one Aquatab. In short, the percent reduction among households that used two Aquatabs was 15% higher than households that only used one Aquatab. This data supports the theory that the jerry cans may have been microbial contaminated prior to use, and suggests that with further use the Aquatabs may further disinfect the product water.

Another explanation for the low percent reductions is outliers in the data. In Kalariga, all but one filtered and chlorine disinfected water sample had a TC concentration below 1,000 CFU/100mL. The one sample with a TC concentration greater than 1,000 CFU/100mL had a value of 42,000 CFU/100mL. This outlier raises the average TC concentration in Kalariga from 215 CFU/100mL (if value was omitted) to 2,039 CFU/100mL. If it was omitted from the data set, the percent reduction in TC would increase from 7% to 90% in Kalariga, which is even higher than the 70% TC reduction in Kakpagyili. This omission would also reduce the total average product water TC concentration to 627 CFU/100mL, which results in an average TC reduction of 76% from the filtered-only water to the filtered and chlorine disinfected water.

As demonstrated, due to the presence of a few heavily contaminated water samples, averaging the TC concentration results is not the most indicative way to understand the results. Table 24 in Section *3.4.2 Microbial Test Results*, shows the percentage of households that had decreased TC concentrations from the filtered-only water to the filtered and chlorine disinfected water, compared with households where the TC concentration remained the same or increased. This table indicates that a higher percentage of households in Kalariga had improved product water than households in Kakpagyili, as a result of using Aquatabs. In Kalariga, 63% of the households had decreased TC concentrations, 13% increased, and 25% remained the same. In Kakpagyili, 34% decreased, 20% increased, and 46% remained the same. The majority of households that remained the same had no TC contamination during the baseline and post-intervention.

Furthermore, Table 25 in Section *3.4.2 Microbial Test Results*, shows the percentage of households that had TC concentrations <100 CFU/100mL for the baseline and post-intervention. In Kalariga, 21% of households did not indicate the presence of TC during the baseline, and 50% did not indicate the presence of TC during the post-intervention, representing a 29% increase. In Kakpagyili, 60% of households did not indicate the presence of TC during the baseline, and 74% did not indicate the presence of TC during the post-intervention, representing a 14% increase.

These two tables show that while the average TC reduction is much greater in Kakpagyili, the use of Aquatabs arguably had a greater effect in Kalariga.

4.2.3 EC Test Results

For the most part, the presence of EC was removed as a result of using Aquatabs. Furthermore, many of the averaged EC results presented in this thesis are misleading. Of the 124 water samples represented in the average water quality data in Figure 27 in Section 3.4 Water Quality Results, only 11 indicated the presence of EC. Because so few water samples indicated the presence of EC, it is difficult to draw significant conclusions concerning household-by-household and average EC concentrations (which is why the TC test is performed to show treatment performance). This explains why the average EC concentrations and reduction/removal values presented in Figure 28 to Figure 32 are erratic.

Of the three dugouts tested, the Kalariga Dam (67 CFU/100mL) and KakDam2 (1,000 CFU/100mL) indicate the presence of EC (KakDam1 did not, which results in a value of <100 CFU/100mL because of the limit of detection with 3M Petrifilm™). The EC value of 67 CFU/100mL obtained in this study for the Kalariga Dam is less than the values obtained by Johnson and Foran in 2007. Johnson performed five tests that ranged from 0-3,600 CFU/100mL and had a mean of 785 CFU/100mL (Johnson, 2007). Foran performed one test on the Kalariga Dam and obtained a value of 754 CFU/100mL (Foran, 2007).

Of the three pre-treatment, storage samples taken, only the sample from Kalariga indicated the presence of EC (100 CFU/100mL). From the data calculated in this thesis alone, it would appear that the water in the pre-treatment, storage vessels in Kalariga is more contaminated than the water from the Kalariga Dam. One possible reason for this is that the storage vessels may be acting as incubators for the bacteria. However, if Johnson's and Foran's results for the Kalariga Dam are used, then the pre-treatment, stored water in Kalariga is drastically reduced when compared with the dam water (769 CFU/100mL to 100 CFU/100mL). Furthermore, it is likely that many of the pre-treatment, storage vessels in Kakpagyili indicate the presence of EC. But because only two samples were taken—and both indicated that no EC was present—the data in this thesis suggests that a significant amount of EC is removed (90%) from the source to the pre-treatment, storage vessels. More water quality testing at dam sources and household pre-treatment, storage vessels is needed.

This limited information also complicates the results when comparing the EC concentration from the pre-treatment, stored water to the filtered-only water samples. Of the 59 filtered-only samples, seven indicate the presence of EC (three in Kalariga and four in Kakpagyili). These seven samples range from 50-200 CFU/100mL. Using an EC concentration of 50 CFU/100mL for samples that did not indicate EC (<100 CFU/100mL), the average filtered-only EC concentration is 60 CFU/100mL, which represents a 10% reduction in average EC concentration from the pre-treatment, stored samples to the filtered-only samples.

Among the 59 filtered and chlorine disinfected samples, only one indicated the presence of EC. However, this one sample had a concentration of 2,200 CFU/100mL, which is an order of magnitude greater than the largest EC concentration from the filtered only samples. As a result, the average EC concentration from all samples increases from 60 CFU/100mL to 86 CFU/100mL as a result of using Aquatabs (43% increase). Similar to the affect of the outlier TC concentration described in the previous section, the average EC concentration is not indicative of the actual treatment. From Table 22 in Section *3.3.2 Microbial Test Results*, 88% and 89% of the households in Kalariga and Kakpagyili, respectively, did not indicate the presence of EC. During post-intervention, the percentage of households that did not indicate the presence of EC increased to 100% and 97%, respectively.

4.2.4 FAC Test Results

According to the CDC, the minimum FAC level in chlorine disinfected water 24 hours after dosing is 0.2 mg/L. Of the 16 households which dosed 24 hours prior to the follow-up survey in Kakpagyili, only ten had a FAC level greater than 0.2 mg/L. Thus, 38% of the households did not satisfy the CDC chlorine limits. Furthermore, from Table 28 in Section *3.4.3 Chlorine Residual Test Results*, the percentage of households that had a FAC level greater than 0.1 mg/L at the time of the visit was 63% and 66% for Kalariga and Kakpagyili, respectively. In this instance and others, the FAC levels from the two communities did not vary significantly.

The CDC also recommends that the FAC residual not exceed 2.0 mg/L 30 minutes after testing. This limit is recommended to ensure that the treated water does not acquire an unpleasant taste or odor. At the time of the survey, seven of the 59 households surveyed had a FAC residual greater than 2.0 mg/L. Some of these households had even dosed their water the day before the survey. However, each of the households also indicated that the Aquatabs improved the taste of the water. Because this limit is imposed more for user acceptance than health, the fact that these households exceeded the limit—and still appreciated the taste of the water—is not of significant importance.

Of particular importance is the fact that 3 of the 59 households had FAC levels greater than 10 mg/L. This exceeds the 5 mg/L limit for FAC residual imposed by Medentech

(Medentech, 2006). It would appear that all three of the households with a FAC residual >10 mg/L overdosed their water. However, each of the three households was asked how many Aquatabs they had used in the previous week, and all three indicated that they had used only one. The households were asked to show the supply of Aquatabs to the surveyor to ensure that only one Aquatab had been used, and all three of the households had nine remaining tablets from the provided strip of ten.

Aside from dosing with multiple Aquatabs, another reason that the FAC level may be higher in these households is that the households dosed with a volume of water less than the suggested 20 L. At the time of the post-intervention household visit, two of these households had 10 L of water remaining in the jerry cans and the third household had trace amounts of water remaining in the jerry can. The households assured the surveyor that they had appropriately dosed a full 20 L of water. However, there is no way to be certain if this was the case. If these households had dosed anything less than 20 L, it would explain why such high chlorine residuals were obtained.

Another explanation for why the chlorine residual was so high for these three households is that the water source already had FAC in it prior to dosing with Aquatabs. However, all three of these households indicated that the water they use for filtering comes from the dugout, which has no FAC residual. The only remaining explanation is that the particular Aquatabs used in these three households released a greater amount of sodium hypochlorite. Specialists from Medentech have assured the author that Aquatabs are manufactured to certified pharmaceutical standards, which ensures their quality and consistency. Furthermore, the greatest FAC residual recorded from a 67 mg Aquatab was 6 mg/L and this Aquatab was used in a vessel that was less than 10 L (Medentech, 2008a).

Therefore, this error is most likely associated with the testing equipment. The instructions released by Hach (included in Appendix E) indicate that the testable FAC residual range for the equipment used is 0-3.00 mg/L (Hach, 2006). Therefore, if a sample exceeds that range, accuracy is no longer reliable. Because of this, it is likely that the FAC residuals from these three samples are lower than the recorded >10 mg/L values.

From Figure 39 in Section *3.4.3 Chlorine Residual Test Results*, there is a correlation between FAC and the time elapsed from the previous dose. Of the 24 households that were asked how many days had passed from their last dose, 10 households had a FAC level greater than or equal to 1 mg/L. All 10 of these households had dosed their water within the previous two days. However, of the subset of households that had dosed their water the day of the actual survey, four of the seven had a FAC level of 0 mg/L. This explains why the averaged FAC levels displayed with the amount of time elapsed in Figure 40 show a lower FAC value associated with dosing the day of the post-intervention, compared with dosing the day before the post-intervention. Contrary to this, the trends are that the FAC levels decrease with time and are mostly gone by the third day after dosing.

The reason for introducing Aquatabs is to disinfect the filtered-only water. Therefore, one would expect there to be a correlation between the FAC levels and the reductions in

TC concentration. From Figure 41, there is a general trend that with higher FAC levels, the % of households with reduced TC increases. When the FAC levels were between 0 and 0.25 mg/L, 32% of the households had reduced TC values and 32% of the households had increased TC values (36% remained the same). However, when FAC levels were between 1.01 mg/L and 2.0 mg/L, 67% of the households had reduced TC values and 8% of the households had increased TC values (25% remained the same). This direct correlation between FAC levels and % reductions—and indirect correlation between FAC levels and % increases—in TC concentrations is fairly consistent over the various FAC ranges presented.

There are similar correlations between the FAC levels and the EC concentration, as well. The only household of the 59 surveyed that indicated the presence of EC in filtered and Aquatab water, had a FAC residual of 0 mg/L. Additionally, this household had dosed their water the same day of the survey, which likely means that the filtered only water was highly contaminated and that all of the FAC released from the Aquatab was consumed in killing a fraction of the bacteria present in the water sample. Also, of the seven households that indicated the presence of EC in the filtered-only water samples and had no EC present in the filtered and chlorine disinfected water samples, four had a FAC level greater than or equal to 0.5 mg/L. The three remaining samples all had a FAC level of 0 mg/L. For these three samples, only one was asked the last time that they dosed their water. This household had dosed their water five days prior to the visit, which explains why their FAC level was so low. It is highly possible that the remaining two households that had EC present in the filtered-only samples and no EC present in the filtered and chlorine disinfected samples and also had a FAC level of 0 mg/L, only had a 0 mg/L FAC level because of the time elapsed from dosing. The CDC indicates that there should be a 0.2 mg/L FAC level 24 hours after dosing, which shows the expected rate of decline of FAC in water.

4.3 Laboratory Test Results

4.3.1 Laboratory Water Quality Test Results

In terms of turbidity, all of the samples were reduced to <5 TU after filtering. The Tanker Truck water had a turbidity of <5 TU prior to filtering, and remained at <5 TU after filtration and chlorine disinfection. The two dugout water samples had turbidity values of 200 and 300 TU prior to filtering. These samples were reduced to <5 TU after filtering and remained at <5 TU after chlorination. The reductions seen in these tests were the type of reductions that were expected in the field (the *Kosim* filter removing all of the turbidity, and the turbidity remaining at <5 TU after chlorine disinfection).

In terms of TC reduction, each of the three tests yielded different results. For the Dugout1-Taha water sample, the presence to TC was removed (<100 CFU/100mL) during filtration. The water entering the *Kosim* filter had a TC count of 100,000 CFU/100mL. After filtration, the TC count was <100 CFU/100mL (and remained at <100 CFU/100mL after chlorination). For the Dugout2-Ghanasco water sample, the TC count increased after filtration and was reduced to <100 CFU/100mL after chlorine disinfection. The water entering the *Kosim* filter had a TC count of 2,150 CFU/100mL. After filtration, the TC count increased to 7,300 CFU/100mL. The reason for this increase is likely that the storage receptacle was contaminated (filtered water for the microbial test was taken directly from the storage receptacle). Similar increases likely occur in community households, so this increase demonstrates the importance of regularly cleaning the storage receptacles with chlorine, prior to filtering. Furthermore, after the contaminated filtered-only water was dosed with Aquatabs, the TC count was reduced to <100 CFU/100mL.

Finally, the Tanker Truck water reduced in TC contamination in each step of the treatment process, but the presence of TC was never completely eliminated. The pre-treatment TC value was 3,000 CFU/100mL. After filtering, the TC count was reduced to 1,700 CFU/100mL and after dosing with Aquatabs the TC count was further reduced to 400 CFU/100mL. These tests demonstrate the benefits of using Aquatabs. For the Dugout2-Ganasco and Tanker Truck water samples, the Aquatabs either completely removed (<100 CFU/100mL) or significantly reduced the presence of indicator organisms (TC).

None of the three water samples indicated the presence of EC at any stage in the treatment process.

Finally, the FAC values of the three water samples was 0.97 mg/L, 1.15 mg/L and 0.69 mg/L for the Dugout1-Taha, Dugout2-Ghanasco, and Tanker Truck water samples, respectively. All three samples were within the CDC recommendations of a minimum FAC value of 0.5 mg/L 30 minutes after dosing and a maximum FAC value of 5.0 mg/L.

4.3.2 Flow Rate Test Results

In analyzing the results from the flow rate tests, it appears that the quality of the water source and the age of the filter both have an effect on flow rate. From Figure 48 in Section *3.5.5 Comparison of Flow Rates*, the clear water samples with new filters filtered the fastest, with an average total filter time of 32 hours. The three dirty water samples (two with high turbidity and microbial contamination and one with no turbidity and microbial contamination) with new *Kosim* filters had an average total filter time of 44 hours. Lastly, the turbid and microbially contaminated water source with a one year old filter required 151 hours to filter just 7 L (1.2 L remained at end of test).

With three never-before-used filters and dirty water samples, the flow rate patterns were similar, which suggests that microbial contamination is the primary inhibitor of flow. The water quality parameters of the three samples are presented in Figure 43 and Figure 44 in *3.5.2 Water Quality Tests on Performance of Combined System.* The Dugout2-Ghanasco water sample had a turbidity of 300 TU and a TC concentration of 2,150 CFU/100mL. The Tanker Truck water sample had a turbidity of <5 TU and a TC concentration of 3,000 CFU/100mL. Because the microbial concentrations are similar and the turbidity of the samples is different, by comparing the flow rate tests of these two water samples one can determine the extent to which turbidity effects flow. In observing

Figure 45, the Dugout2-Ghanasco water sample actually filtered faster than the Tanker Truck water sample, which indicates the microbial contamination affects flow while turbidity does not. If this is the case, then one can conclude that the presence of bacteria in water samples increases the required flow time by 38% (32 hours to 44 hours).

However, the primary reason that the flow rates differ is because of compositional variability among filters. Assuming that microbial contamination is the primary inhibitor of flow, one would expect the Dugout1-Taha water sample to filter slower than the Dugout2-Ghanasco sample because its TC value was 100,000 CFU/100mL (47 times greater than the Dugout2-Ghanasco value, 2150 CFU/100mL). However, this sample actually filtered the fastest of the three contaminated water samples with new filters. Furthermore, the flow rate of the same clear water through the three new *Kosim* filters were also was different (see Figure 45).

As discussed in Section *1.3.3 Ceramic Filter Composition and Production*, the clay and sawdust used in manufacturing filters is sieved to a particular range. Even though this process achieves a particular size range, the possibility remains that some pots may be primarily composed of the smaller particles in that range and some pots may be primarily composed of the larger particles in that range. Moreover, clay composition would likely differ from batch to batch. This would lead to varying pore sizes, which would lead to varying flow rates.

Therefore, the most likely explanation as to why the flow rates from the three contaminated water sources differed is that the pots themselves were different. Given that the ceramic pots have different properties, it is possible that turbidity and microbial contamination affect flow rate differently than as described above. For example, if the pot used to filter the Tanker Truck water had the smallest pore sizes of the three filters, then that would explain why it yielded the slowest flow rate for the first 24 hours of filtration. Likewise, the pot used to filter the Dugout1-Taha water likely had the largest pore size, which would explain why this pot had the fastest flow rate throughout the duration of the testing. If these hypotheses are true, then the affect of turbidity and microbial concentration with respect to flow rate cannot be understood from these tests. To correct this problem, one would need to filter each of the three water samples through the same filter, ensuring that the filter was properly cleaned between each sample. Alternatively, one could test a number of new filters with clean water and select a set that showed identical initial flow rates.

Another conclusion from these three tests is that higher flow rates do not compromise performance. As discussed in Section *1.3.3.3 Pore Size*, if the pore size in the ceramic vessels is too large, then the flow rate will be higher (which is good), but the ability of the filter to remove turbidity and microbes will be reduced. This is why the filters are supposed to have specific pore sizes, and thus specific flow rates. However, from the three contaminated samples—with new filters—in this study, the filter that performed the best at removing turbidity and microbial contamination was the filter with the highest flow rate. Therefore, for ceramic filters with flows in the first hour of 0.8-1.7 L, filters with higher flow rates are preferred.

Over long periods of time, turbidity and microbial contamination have lasting effects on flow rate. This is a result of the fact that filtration occurs throughout the depth of the ceramic filter. To clean the filters, the inside is thoroughly scrubbed. However, the filtered particulates and bacteria within the walls remain. Therefore, one would expect that with time these accumulating impedances would greatly diminish the amount of flow through the ceramic, as was demonstrated when the author tested a one year old filter.

A one year old filter from Kalariga required over six days to filter 7 L of water and there was still 1.2 L of water remaining in the filter at the conclusion of the test. This is three times as long as the filtering time of water of similar quality through a new filter. The previous owner of this filter complained about the speed of her filter, so it is possible that the original composition of this particular filter is the primary reason for the slow flow rate. However, the flow rates given by this filter are drastically lower than the flow rates given by the three new filters with water of similar quality, which suggests that the filtered particulates and organic matter are the principle causes. It is uncertain as to how frequently the household who used this filter cleaned it.

The technical specification sheet for the *Kosim* filter (see Appendix F) suggests that flows in old filters can reduce to 0.5 L/hr over time, but that they are restored by scrubbing (Jackson and Murcott, 2007). With this one year old filter, the flow rate was reduced to 0.23 L/hr, despite cleaning the filter. It is possible that the flow rate through this filter could have been further regenerated by backwashing; however, this cleaning method was not performed while in Ghana.

Another observable trend from the flow rate tests performed is that the flow rate decreases exponentially with time for all water samples tested. This exponential behavior is expected as gravity is the driving force in filtration. Because the filter is shaped like a flower pot and water is primarily filtered through the sides of the filter (Van Halem, 2006), it is expected that a more full pot (more water contact area) would filter water quicker than a less full pot. Furthermore, when the pot is full, there is greater pressure head in the filter, which facilitates the filtration.

This exponential behavior can be observed in Figure 48 from *3.5.5 Comparison of Flow Rates*, where the flow rate decreases with each hour. For the three contaminated water sources, the average percent reductions are 23% from the first hour to the second hour, 24% from the second hour to the third hour, and 15% from the third hour to the fourth hour.

With such high drops in flow rate, a more efficient means of filtering would be to fill the filter to the top as frequently as possible to maximize the flow rate. This poses certain challenges in terms of cleaning. If the filters were continually filled, then there would not be an opportunity to clean the filter after each time it was used. Ultimately, the filter would clog and the flow rate would be impeded. To prevent this, filters should be filled as frequently as possible, but after a series of fillings, the remaining water in the filter should be poured back into the pre-treatment storage vessels; the filter should then be cleaned and filled again to resume filtration. This method will be discussed in further detail in the following chapter.

5.0 Conclusions/Key Points

The combined *Kosim* filter and Aquatabs treatment system is an effective household water treatment system and is relevant for implementation in Northern Ghana, particularly to lower class and lower middle-class communities who can afford to pay for the combined system. This conclusion is supported by the following key findings:

- Average TC concentration was reduced by 50% from baseline (filtered-only) to post-intervention (filtered+Aquatabs) from all 59 households
- 46% of households experienced reduced TC concentrations in Aquatabs treated water, while 37% remained the same as post filtered-only water (most of those households had no contamination in either sample) and 17% increased
- Percent of households that did not indicate the presence of TC (<100 CFU/100mL) increased from 44% to 64% from baseline to post-intervention
- EC present in only 2% (1/59) of post-intervention water samples, compared with 12% (7/59) of filtered-only water samples
- 62% (10/16) of households had a FAC level greater than 0.2 mg/L 24 hours after dosing, at time of post-intervention visit
- 64% of households had a FAC level greater than 0.1 mg/L at time of post-intervention visit (0.1 mg/L FAC was the benchmark used for randomized chlorine testing in the CDC study in the neighboring village of Bipelar in Northern Region, Ghana in 2007)
- Among households with a FAC residual in treated water between 0 and 0.25 mg/L, 32% of households had reduced TC concentrations, while 32% had increased TC concentrations
- However, among households with a FAC residual in treated water between 1.01 and 2.00 mg/L, 67% of households had reduced TC concentrations, while 8% had increased TC concentrations
- All survey respondents indicated that Aquatabs "improved the taste of the water" and that they "would recommend Aquatabs to others"
- 33/35 (94%) of lower middle-class survey respondents were willing to pay the full GHC 3 for 100 Aquatabs, while 6/24 (25%) of lower-class survey respondents were willing to pay same price (100 Aquatabs is sufficient for 1 year of treatment with the combined system)

6.0 Future Research Needs

6.1 Further Analysis of Combined Kosim Filter and Aquatabs

This pilot study alone does not provide a complete analysis of the effectiveness and user acceptability of the combined *Kosim* filter and Aquatabs system. It is important to gather more field data on this combined system in order to form more complete conclusions. Moreover, there were important lessons learned during this study and as a result, there are ways a new study could be improved.

6.2 Further Flow Rate Tests

One major research need is to better understand the flow rate through the *Kosim* filter. In this regard, it is important to better understand the extent to which turbidity and microbial contamination affect the flow rate of new filters and how prolonged use affects flow rate with water of similar quality to that in Northern Region, Ghana. One should also determine the most efficient filter filling strategy between cleanings, in order to maximize the amount of water households can obtain, which will be explained further in Section *6.2.4 Optimal Filling Frequency.*

6.2.1 Initial Flow Rate Tests

In this study, six new *Kosim* filters' flow rates were tested, three with clear water and three with microbially contaminated (and in two cases, turbid) water. With clear water sources, two of the three *Kosim* filters were within the 1-2.5 L/hr requirement for CTL filters. The third filter had an initial flow of 3.10 L/hr. On the other hand, with turbid and microbially contaminated water sources, one of the two Kosim filters was within the 1-2.5 L/hr requirement. The other filter had an initial flow of 0.93 L/hr. Additionally, the initial flow rate of the clear, microbially contaminated water source yielded a flow rate below the 1-2.5 L/hr requirement (0.76 L/hr).

Further research and quality control steps should be taken to ensure that the initial flow rate falls within the designated range. If the flow rates are found to be greater or less than 1-2.5 L/hr, then the technical specifications should be altered accordingly. However, if a 1-2.5 L/hr flow rate is desired, and it is found that the flow rate of the manufactured filters is less than or greater than that range, then the composition of the filters must be monitored and/or manufacturing controls put in place.

6.2.2 Affect of Turbidity and Microbial Contamination on Flow Rate

Another research need is to better understand how the turbidity and microbial contamination of water sources affects flow rate. From the data in this study, the conclusion is that—among new filters—turbidity of water sources does not affect flow rate, but microbial contamination does. However, this conclusion is likely false because it goes against the fact that microbes are associated with particles. Therefore, the association between flow rate and water quality should be further researched by testing the flow rate of different water sources through the *same* filter or a number of filters with similar baseline flows.

6.2.3 Affect of Use on Flow Rate

Additionally, it would be beneficial to determine how use and maintenance practices affects flow rate. This research study concludes that over time the ceramic filter becomes clogged, resulting in a decreased flow rate. However, the flow rate test in this study was performed on a one year old filter, which was acquired from a community member who had specifically complained about the speed of her filter. Therefore, this filter may have originally been slow.

Piaskowy has performed some tests on the affects of use on flow rate, as discussed in Section *1.3.4 Flow Rate*. However, turbidity of the source water used in Piaskowy's study is significantly less than the water sources in this report. Therefore, the use and flow rate conclusions from her study may not be applicable to higher turbidity waters as are found in the Northern sector of Ghana.

6.2.4 Optimal Filling Frequency

Lastly, in terms of use, it would be beneficial to know the optimal filling frequency of the *Kosim* filters. Most households surveyed in this study fill their filters, allow all of the water to filter, clean their filters and repeat (four households continually topped-up their filters). Given that the flow rate reduces from 1.1 L/hr within the first hour to 0.5 L/hr from the third to the fourth hour (from the microbially contaminated water sample tests performed in Ghana with new filters), the best filtering strategy would be to continually top up the filter for a period of time, empty all the water from the filter, clean the filter, fill it to the top again and repeat. However, this would be incredibly tedious, so there must be a user acceptability consideration. Perhaps the community members would be comfortable topping up their filters every few hours. If this was the case, then a test should be performed to determine the appropriate number of times the filters should be topped up before cleaning, to achieve the optimal flow rate. With this information, households would be better equipped to filter large volumes of water in times of need. PHW recommends continually topping up filters between cleanings; however, an optimal frequency has not yet been determined.

6.2.5 Different Demographic Communities

This pilot study focused on two communities—one lower class and one lower middle-class. Both communities derived a major portion—if not all—of their drinking water supply from unimproved surface water dams. This was an appropriate focus of this study as these are the target demographics of PHW. However, middle and upper-class communities could have an interest in the combined Kosim+Aquatabs system and further research should be investigated.

7.0 Recommendations for Future Research Needs

7.1 Recommendations for Further Research of Combined *Kosim* Filter and Aquatabs Treatment System

7.1.1 Improvements to Study Design

In order to proceed with the analysis of the combined *Kosim* filter and Aquatabs treatment system, several limitations in the study design highlighted in this report should be corrected. One of the largest problems associated with this pilot study concerns the 20 L jerry cans that were distributed to the households. Despite the fact that the jerry cans were washed prior to distribution, there remains a possibility that some of them were microbially contaminated prior to use. If this was the case, then the microbial test results from the filtered and chlorine disinfected water would not be indicative of the actual performance of this combined system. In order to correct this problem in future studies; one should first thoroughly clean the jerry cans with chlorine and then rinse them. Afterwards, the jerry cans should be filled with water from the *Kosim* filter with no turbidity and no microbial contamination. The water should be swirled throughout the jerry cans and tested for microbial contamination to ensure that they are clean. Only then should they be distributed.

Another variable that may have affected the performance of this combined system is the length of time over which this study was conducted. The households were told during the baseline that surveyors would be returning in one week to test their water and answer any questions they may have. Ideally, the length of time between baseline and post-intervention would have been longer, however, there was only a certain amount of time the author had in Northern Region, Ghana. As a result, households may have rushed the water treatment process in order to have treated water available for testing during the return visit. Alternatively, they may have thought that the *Kosim*+Aquatabs system was a silver bullet that did not benefit from the settling that normally occurs in their storage vessel everyday practice. One more possibility would be that as the dry season was progressing, their dugout source was drying up and turbidity levels were increasing. Any of these three cases would result in more highly turbid water added to the filter, which would potentially result in more highly turbid filtered water, and consequently, product water with a higher microbial contamination (due to the natural binding of bacteria to the suspended particulates). This hypothesis is supported by the fact that the number of households with turbid water increased from the baseline to post-intervention.

Another limitation was the time and resources constraint. One must allow an appropriate amount of time and financial resources to complete a study of this nature. Ideally, during the baseline, the households would be told that someone would be coming back at several points over a period of 6 months to 1 year. That way, the households would not know when to expect the post-intervention visit, and thus could not prepare (i.e. ensure that they had treated water available for testing). This would provide further insight into just how effective this combined technology is, and would also allow the researcher to determine if the households are regularly using the system.

Furthermore, for better comparisons between filtered-only samples and filtered and chlorine disinfected samples, both samples should be tested during the same visit. This would provide a more accurate comparison between non-chlorinated and chlorinated water samples because the quality of the pre-chlorinated water would be more similar to the filtered-only water.

7.1.2 Improvements to Survey Process

There are also numerous ways in which the survey process could be improved. A simple correction should be made concerning the introduction of the survey process. The interviewer should stress the fact that the survey is confidential and that it is important for all responses to be given honestly. These two points should be repeated at different points in the survey when necessary (e.g. asking about diarrhea cases).

Furthermore, it would be ideal to have native-born Ghanians trained in how to conduct the entire survey and water testing by themselves. The author observed many survey biases attributable to the fact that a white person—together with a Ghanian translator—was leading the survey team and testing the water. Therefore, if a local Ghanian were to perform these tasks, it is thought that these biases would be diminished, resulting in more accurate survey responses. This would require appropriate training, with role-play simulations and a pre-test to ensure proper survey implementation.

Another limitation of this research design was that there were different members of the survey team conducting the survey at different times. As a result, the surveyors may have translated or formed questions differently, which would result in different responses. Correcting this problem would require the use of only one surveyor, and ensuring that the surveyor formed the questions the same way each time the survey was conducted. The interviewer should also be educated on how to probe respondents when incomplete responses are given. Lastly, whoever trains the interviewer should stress the importance of maintaining a constant speed in each interview. This method would also require managing and monitoring the trained survey team, which requires time and resources not available in this study.

Another means of eliminating survey bias is to sell the products to the households, rather than provide them for free. If the community members are purchasing the products, then they would likely feel more entitled to provide negative feedback concerning things like functionality, effectiveness, taste, etc. However, there are also complications associated with selling the products. For one, the author of this report felt it was important to have 100% community participation so that households could discuss the products within the communities. If the products are not distributed for free, then it would be more difficult to achieve this.

From the outset, the baseline and follow-up surveys were conceived of as qualitative surveys, not quantitative ones. The advantages of a qualitative survey are that it allows for observable behaviors, cultural patterns, motivations and attitudes to be gauged, and for the surveyor to analyze situations within the context that the survey is being conducted (Marsland, 2000). A future survey could improve on this qualitative approach by eliminating the survey biases discussed previously and in the following section. Alternatively, a quantitative analysis involving randomized sample populations could be central to the survey design. If this were the case, more credible results could be obtained concerning the statistical measures in this study (rate of use of products, different adoption and sustained use rates by different demographics, water quality test results, etc.), and further trends could be assessed (Marsland, 2000).

There are many ways in which the individual survey questions could be improved. Question 2 from the baseline survey ("From where do you collect your water?") should specifically inquire from which dugout the household collects their water. Many communities use multiple dugouts for water collection. In this research study, households in Kakpagyili collected water from one of two dugouts, which vary in water quality. As a result, it is difficult to compare the treatment results among the stages of treatment because the water source is uncertain.

Furthermore, Question 15 (also from the baseline survey) should be reworded. It asks, "Before you got the Kosim filter, did you treat the water at all?" It proceeds to ask, "Did that work?" The problem with this question is that many of the households only indicated one method they used to treat their water. All of the households surveyed had Guinea Worm Cloth Filters distributed by the Carter Center. Therefore, many of the households chose to only refer to these filters when asked about their previous treatment technology. It was later determined that many of the households also previously used alum, in addition to their cloth filters. This question should be changed from an "open" question to a "closed" question, where the respondents are given a list of technologies and asked to identify the ones they previously used. For example, the questions could be, "Which of the following water treatment technologies did you use prior to the *Kosim* filter: cloth filters, alum, biosand filter, or another technology?"

Additionally, all of the households said yes when asked, "Did that work?" The purpose of this question was not to determine whether this treatment technology worked, but rather, whether the community members thought that their previous technology was sufficient for drinking water treatment. Therefore, this question should be changed by incorporating the "subjective continuum scale", where the respondents are asked to choose from a list of adjectives describing the level of treatment. For example, the question could be changed to, "Choose one of the following responses. Did your previous treatment method perform very poorly, poorly, ok, good, or very good at treating your drinking water?" If this question was asked, and the same continuum scale was used to describe the treatment effectiveness of the sole use of the *Kosim* filter during the baseline survey, a more thorough comparison of the subjective improvement of the *Kosim* filter would be achieved.

Additionally, it is unclear whether households were entirely forthright concerning diarrheal occurrence. If they were not, it is thought that they might be more inclined to provide honest responses if asked by someone of native descent. Furthermore, a specific time scale for diarrhea occurrence should be given. For example, this question could be changed from, "Has anyone in your household had diarrhea recently?" to "Has anyone in your household had diarrhea in the past two weeks?"

Some changes should also be made to the follow-up survey. For one, bias in Question 3 ("Did the Aquatabs improve the taste of the water?") should be eliminated. Using a word with positive connotations like "improved" may communicate to the respondent that a positive answer is expected. Therefore, the sentiment of this question should be changed to remain neutral. Similar to the rewording of questions relating to treatment technologies described above, this question could be changed to, "Choose one of the following responses. The Aquatab treated water tastes: very bad, bad, ok, good, very good?" If this same type of question was asked regarding the taste of the sole use of the *Kosim* filtered water during the baseline survey, one would better be able to determine if the households like the taste of the Aquatab treated water. Also, it is important to ask every household when they last added Aquatabs to their water. In this study, only 24 of the 59 households were asked when they last dosed their water. This information is critical when trying to analyze the FAC results.

Finally, if the survey responses are validated, then the responses could be trusted with more reliability. This could be achieved by asking a question that could be verified, for example, by direct observation

7.2 Recommendations for Further Flow Rate Tests

7.2.1 Recommendations for Initial Flow Rate Tests

To address the need to better understand initial flow rates through *Kosim* filters, one must either acquire a large number of new filters—or work directly with the manufacturer—and test them before they are used in the communities. This test would be simple to complete, because one would only need to check the flow rate for the first hour. An important consideration is to ensure that the ceramic filters are wetted throughout the thickness prior to beginning filtration.

7.2.2 Recommendations for Affect of Turbidity and Microbial Contamination on Flow Rate

To determine how turbidity and microbial contamination affect flow rate, one should use the same filter for a series of tests. Ideally there would be four water samples tested. Water Sample #1 would have a high turbidity and microbial contamination. Water Sample #2 would have the same turbidity as Water Sample #1, but no microbial contamination. Likewise, Water Sample #3 would have the same microbial contamination as Water Sample #1, but no turbidity. Lastly, Water Sample #4 would have no turbidity or microbial contamination. The ceramic filter should be wetted prior to each flow rate test. Also, it is of paramount importance that the ceramic filter is scrubbed thoroughly after each flow rate test (even to the point of removing a micro layer of ceramic). To test the effectiveness of the cleaning, the first flow rate test should be repeated at the end of testing to ensure that the flow rate is the same. If these four tests (five with the repeat test of the first water sample, to ensure effective cleaning) were performed, one would better be able to assess how turbidity and microbial contamination individually affect the flow through *Kosim* filters.

7.2.3 Recommendations for Affect of Use on Flow Rate

Finally, arguably the greatest need in terms of further flow rate research is to determine how use affects flow rate. Ideally, this research could be performed over a long period of time. In this case, one could test the flow rate of a filter that is constantly in use (filtering water of similar quality to the water in the Northern sector of Ghana) every month or so and compare how the flow rate changes. If one only has a certain amount of time to conduct this research, then a sample of old filters would need to be acquired and tested for flow rate. The primary challenges associated with this method is that it is impossible to understand how the flow rate for each particular filter has changed over time because each filter has different compositional properties, and thus has different initial flow rates.

Piaskowy performed flow rate tests on water over a three month period. However, the source water used for testing had turbidity values between 8.63-16.37 NTU, which is significantly less than the turbidity values seen in many dugouts in the Northern sector of Ghana. Therefore, this test should be performed with water of similar turbidity to the dugout water used in the rural communities in Northern Ghana.

7.2.4 Recommendations for Determining the Optimal Filling Frequency

In order to determine the optimal filling frequency of the *Kosim* filters, a few steps must be performed. The first step is determining how frequently the households would be willing to fill their filters. The most likely method for gathering this information would be to survey a sample of households. After this information is gathered, a flow rate test should be conducted where the filter is filled, it is allowed to filter for the specified time, it is filled again, and the process is repeated. The amount of water that is filtered between each filling interval should be calculated to determine at what point it would be necessary to empty the contents of the filter and clean it. In performing this test, it is important to remember that the households can only add water to the filters during waking hours.

8.0 Recommendations for PHW

There are also several ways in which PHW could improve their practices:

1. Possibility of combined alum and Aquatabs system
2. Further education of *Kosim* filter owners
3. More frequent interaction/follow-up with village volunteers
4. Focus on seasonal trends in sales

These four suggestions will be discussed in further detail in the following sections.

8.1 Possibility of Combined Alum and Aquatabs System

It is possible that a combined treatment system of alum and Aquatabs would be more practical in the Northern sector of Ghana, and should be considered as a product for sale by PHW. In the combined *Kosim* filter and Aquatabs system, the primary purpose of the *Kosim* filter is to remove turbidity, while the primary purpose of the Aquatabs is to disinfect. Therefore, it would be worthwhile to understand if there is a cheaper and more efficient means of removing the turbidity. As discussed in this thesis, there are many challenges associated with working with the *Kosim* filter. The most important challenge has to do with the flow rate. According to the survey responses, the average household only filters 23.5 L per week. This value is not sufficient for households with approximately 12-14 people. With alum+Aquatabs, households could produce significantly more treated water.

However, similar to the *Kosim* filter, there are also certain challenges associated with alum. From speaking with locals in Northern Ghana, many people do not like the taste of alum and some said it caused them to have diarrhea. However, if Aquatabs were added to water that had already been treated with alum, then the taste complaint might be mitigated (every survey respondent in this study liked the taste of the Aquatab dosed water). Moreover, the issue of alum causing diarrhea is likely due to overdosing, so it could potentially be overcome with proper dosing. Another challenge is that people in Northern Ghana tend to like durable products that they only have to purchase once and can then use for a long period of time, compared with consumable products that must be repeatedly purchased (Green, 2008). However, similar to alum, Aquatabs are consumables. So any household that prefers durable water treatment technologies over consumable products would likely not use the combined *Kosim* filter and Aquatabs system anyway.

Table 33: Cost Comparison Among Different Treatment Technologies Evaluated at Net Present Value (NPV)

	Cost (GHC)[5]				
Treatment System	Capital Cost	Weekly Cost	Cost After 1 Year	Cost After 5 Years	Cost After 11+ Years
Alum+Aquatabs		0.09	4.50	17.50	28.00
Kosim+Aquatabs	17.50	0.04	19.20	24.00	28.00
Kosim only	17.50		17.50	17.50	17.50

Furthermore, when the cost is factored in, the combined alum and Aquatabs system is significantly cheaper than the *Kosim* filter and Aquatabs system. Most rural community members already have storage vessels and portable vessels for water collection. Therefore, there is no capital cost associated with the combined alum and Aquatabs system. Each Alum ball costs between 10 and 30 pesewas (GHC 0.10 and 0.30), which is the equivalent of 10 and 30 cents (Alum Fact Sheet, 2007, Included in Appendix H). These alum balls are able to treat two containers of 40 L of water. For comparison, the *Kosim* filter costs GHC 15-20 as a one-time cost (or approximately US $15-20). For calculations, it was assumed that both combined systems are used to treat the amount of water produced from the regular use of the *Kosim* filter in one week (23.5 L). A *Kosim* price of GHC 17.50 and an interest rate of 14.25% were used (Bank of Ghana, 2008). Additionally, a cost of GHC 0.20 was used for each alum ball and GHC 0.03 for each 67 mg Aquatab.

From Table 33, the combined alum+Aquatabs system is affordable. Bringing repeated costs back to the Net Present Value (NPV), it would take 5 years for the alum+Aquatabs system to be as expensive as the *Kosim* filter alone. Furthermore, it would take 11.25 years for the alum+Aquatabs system to be as expensive as the *Kosim*+Aquatabs system.

The real benefit of the combined alum and Aquatabs system is that it could potentially provide significantly more water than the combined *Kosim* filter and Aquatabs system. Some additional benefits of the combined alum and Aquatabs system is that alum is already widely used in Northern Ghana, and has been for a long time. With a rural sample size of 119, Green found that 44% of rural Ghanians in Tamale area currently use alum (Green, 2008). Therefore, similar to the combined *Kosim* filter and Aquatabs system, the communities would only need to be educated on one new product. Also, Ghanians tend to appreciate practices that have been passed down through the generations, so there is already a certain amount of respect for the use of alum as a water treatment process (Alum Fact Sheet, 2007).

There are some problems associated with this combined system. For one, it requires a significant amount of work to stir the alum coagulant, wait for the particles to settle, and then decant the treated water. Secondly, if not done properly, then all of the turbidity may not be removed, which would affect disinfection. Taste and inappropriate dosing issues have already been highlighted.

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[5] 1 GHC = 1.025 US Dollar on May 19, 2008.

In order to assess the technical performance and user acceptability of a combined alum and Aquatabs system, one should perform a similar procedure to the one outlined in this thesis, while at the same time correcting for the study design limitations already highlighted. Ideally, communities of varying economic classes could be targeted, who use dugouts as their primary water source and who use only Guinea Worm Cloth Filters and alum as their water treatment technologies. One would also want to include middle and upper-class demographics who are supplied with municipal water serving as potential control.

It would also be important to sell—not donate—the alum and Aquatabs to the community members. One of the limitations of this study was that the Aquatabs were given away for free, which generated certain biases when following up with the community members. The present study design sought to take advantage of the 59 households in Kalariga and Kakpagyili in possession of *Kosim* filters and sought 100% participation of those households by giving each participating household a six-month supply of free Aquatabs. The combined alum and Aquatab study design could visit households who already use alum for water treatment, educate those households about Aquatabs, and sell them a specific quantity for the duration of the study. Because they are no longer free, there will not be 100% participation; however, it is thought that by conducting the study this way, the user acceptance results would be more indicative than with free distribution.

As a pilot study, the researcher could sell one strip of ten Aquatabs to each household. This would only amount to a cost of 30 pesewas (GHC 0.30) in addition to the cost of the alum balls, which many households would likely be able to afford. It would also be enough for a two week pilot study (one week surveying, educating, distributing, and testing the alum only water, and another week surveying, inquiring, and testing the alum and Aquatab water). If this test were completed, it would provide the user acceptability results (in addition to water quality results) necessary to determine if this combined system is more or less appropriate than the combined *Kosim* filter and Aquatabs system.

Additionally, the survey alterations described in Section *7.1.2 Improvements to Survey Process* should be made.

8.2 Further Education of *Kosim* Filter Owners

From the data in this report, there are several ways to improve the effective use of the *Kosim* filter. For one, the households should be made aware of the benefits associated with allowing dugout water time to settle in the pre-treatment, storage vessels. This thesis and other research highlight the water quality benefits associated with gravity settling. If the households were told to allow for at least one day of storage time, the water added to the *Kosim* filters would have significantly reduced turbidity (55-66%, Doyle, 2007, Loslebon, 2008) and microbial contamination, which would result in cleaner filtered water and would also prolong the life of the filters and lessen the frequency of cleaning needed, as they would become less clogged. This consideration is entirely possible as many households have multiple water storage vessels. If they filled each vessel at a different time, then they could easily ensure that gravity settled water was always available.

Another consideration pertains to the frequency that the filter is filled. As described in the previous sections, the optimal means to obtain filtered water is to continually fill the filters for a period of time, then to empty the source water, clean the filters, and repeat. While this is understood by PHW, it was not well communicated to the households visited in this study. Therefore, the salespeople for PHW and community liaisons should ensure that this point is highlighted during community presentations and follow-up visits.

If these two strategies were explained to the communities, then the users could potentially produce more water of better quality, which would enhance the perception of the *Kosim* filter technology.

8.3 More Frequent Interaction/Follow-up with Village Volunteers

Another need for PHW is to have mandatory follow-up visits with communities possessing *Kosim* filters. In one community surveyed in this report (which had had their filters for one year), 21% of the filters were broken and 17% were broken to the point where they were no longer functional. All of these breakages were easily replaceable and the community members were willing to purchase new parts. Therefore, to ensure that households are able to continually use functioning filters, it is important for PHW staff to perform regular follow-up visits with the village liaisons. Currently, follow-up visits are performed. However, there needs to be a system where communities can purchase new parts at designated times. For example, perhaps communities should be revisited every six months. If the community members knew that they could purchase new parts every six months, then they could depend on their filters being fixed at that time. Another option would be to distribute parts to the village liaisons, have him/her sell the parts, and then collect the money directly from the village volunteer during the follow-up visit. This would allow households to continually have functioning filters.

8.4 Focus on Seasonal Trends in Sales

The primary means of income for many rural Ghanians in Northern Ghana is by selling their crops after the harvest. However, due to the seasonal rainfall trends and the lack of irrigated agriculture, the harvest only occurs once in Northern Ghana (from September to Juanuary). Once the crops are harvested, they are sold in the market within the next couple of months. As a result, many rural Ghanians in the Northern sector spend most of the year without available cash, but have an abundance of money at a certain point in the year. PHW could greatly enhance their sales in rural, agricultural communities if they were able to take advantage of this seasonal trend in finances.

9.0 Closing Words

A pilot study of 59 households in two communities—Kalariga and Kakpagyili in Northern Region, Ghana—was conducted by the author, together with local guides and a translator, during January, 2008. The study considered both the technical efficacy of the combined *Kosim* and Aquatabs treatment system and its user acceptability. Key findings are that the system is an effective household system and is accepted by the users. The addition of Aquatabs removed 50% of TC from the *Kosim* filtered water and the percentage of households with no TC increased from 44% to 64%, as a result of using Aquatabs. Furthermore, households unanimously approved of both the taste and treatment level of Aquatab dosed water. It is relevant for implementation in Northern Ghana, particularly to lower and lower middle-class communities and may be more widely applicable to other market segments as well.

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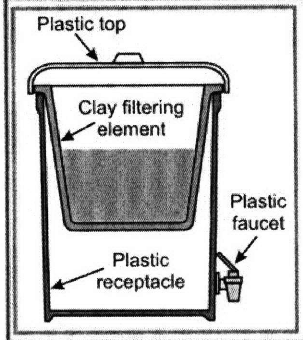
11.0 Appendices

Appendix A: Instructions for Use of Kosim filter (PFP, 2007)

HOW TO USE YOUR FILTRON

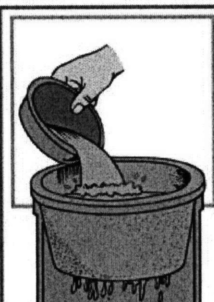


1. Washing the RECEPTACLE

Wash your hands with soap .
Attach the spigot (faucet) to the plastic receptacle.
Fill the receptacle one quarter full with water and add two tablespoons of chlorine bleach.
Leave this for thirty minutes to disinfect the plastic receptacle.
Use this water to wash the entire inside of the plastic receptacle and the lid with a brush or cloth.
Drain the water out through the spigot to disinfect.
If you do not have bleach, wash the receptacle and lid with soap and water as described above.
You can use either filtered or boiled water to rinse.

2) Place the plastic receptacle in a location that is stable and out of the way of activity.

Using both hands on the edge of the clay filter, place it on the mouth of the receptacle.



3) To get rid of the clay taste of the new filter, fill it with water and drain through the spigot. Repeat until all taste is gone.

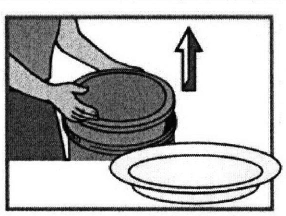
4) If your water is turbid, strain it through a clean piece of fine cloth. Tie the cloth in place around the outside of the plastic receptacle.

5) Keep your filter filled and covered at all times.

The filter will flow more rapidly (one to two liters per hour) if it is kept full.

Remember: Before serving water wash your hands and cups with soap.

HOW TO CLEAN YOUR FILTRON

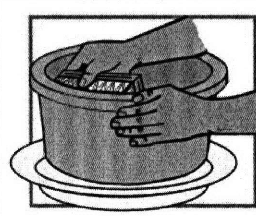


Cleaning your CLAY FILTER

1) When the flow rate decreases, it is a signal that the pores of the clay filter are clogged.

To wash:

- **Do not lift the clay filter when it is full of water.** Wait until the clay filter is empty and there is filtered water in the plastic receptacle.
- Wash your hands with soap.
- Remove the clay filter from the plastic receptacle and put it on a plate that has been washed with filtered water.



- Pour a few inches of filtered water back into the filter.
- Scrub the filter with a stiff laundry brush on the inside and outside to remove any debris or particles.
- Do not worry if some of the clay comes off. It means you are scrubbing well.
- Rinse with filtered water until the water is clear.

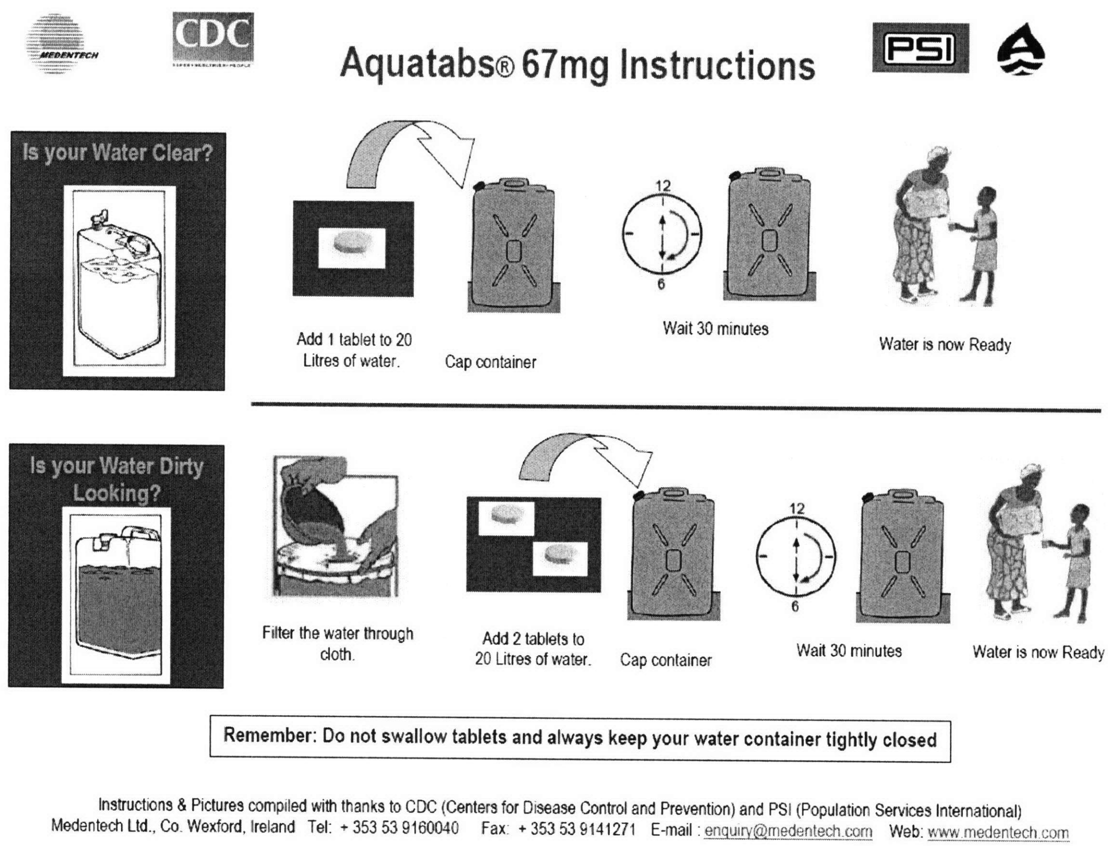
Attention! Never use chlorinated water or soap to wash the clay filter.

3) **Washing the PLASTIC RECEPTACLE**

Wash the plastic receptacle each month with chlorinated water or with soap as explained in part 1. Once you have finished washing, return the clay filter to the plastic receptacle to begin use.

Attention: The Filtron filter generally functions well for a year and a half or more. If you have problems, contact the organization that distributed your filter for advice on what to do.

Appendix B: Medentech's Instructions for Use of 67 mg Aquatabs



Appendix C: Baseline Survey

Ghana Household Survey: Initial, Baseline Survey

- My name is Andrew Swanton, I am a student from MIT in the United States, and I am doing research on the Kosim filter
- Participation in this study is voluntary; you may decline to answer/stop survey at any time, and the Aquatabs will be taken away
- All information will be kept confidential
- Please be honest with responses
- Do you understand? Are you willing to participate?

Yes	
No	

(If no, thank and close)

Name of person interviewed:__________ ______________
Last Name **First Name(s)**

Age and gender of respondent: ________________________

Household status: ______________________________

Filter Use

1. Can you show me the water you use for drinking?

OBSERVE:

   a. Is the ceramic filter installed in the unit?
   b. Is the filter covered with a lid?
   c. How much water is in the receptacle?

2. From where do you collect water?

3. Is your filter working?

4. When did you purchase your filter?

5. Do you ever drink unfiltered water?

   a. If yes, why?

6. Can you show me the water that you use for cooking/dishes/washing hands?

   a. Where does this water come from?
   b. Do you filter this water?

OBSERVE:

c. Does the water appear turbid?
d. Is the water being stored in a covered container?

7. How many times per week do you add water to the Kosim filter?

Filter Maintenance

8. When was the last time you cleaned the filter and the storage unit?

9. Did the sales person give you materials to explain how to clean the filter?

    a. If yes, can you please show me these materials?

10. Did this person come to your house and show you how to clean the filter?

11. Can you act out for me how you clean the filter?

OBSERVE:

a. Do they use the provided brush?
b. Did they clean the storage unit?
c. Did they use soap and filtered water to clean the storage unit? (SHOW US)

Perception

12. Do you like the taste of filtered water?

13. Is the filter easy to use?

14. Have you had any problems with the filter breaking?

    If yes, can you show me what the problem is/was?

15. Before you got the filter, did you treat the water at all?

    If so, how?
    Did that work?

16. When was the last time someone in your house had diarrhea?
    a. how old was this person?

Thank you!

TAKE WATER SAMPLES FOR ANALYSIS IN THE LAB

Take a sample of the raw water and if they treat water take a sample of that also.

- Sample number on bottle....................................... □Raw water □Treated water
- Sample number on bottle....................................... □Raw water □Treated water

Remember to keep the samples in the cooler and do not expose the bottles to sunlight. They must be kept in a cool and dark place until analysis.

Sample time:...

Appendix D: Follow-up Survey

Ghana Household Survey: Follow-up of Households Using the Combined *Kosim* Filter and Aquatabs System

- My name is Andrew Swanton, I am a student from MIT in the United States, and I am doing research on the Kosim filter
- Participation in this study is voluntary; you may decline to answer/stop survey at any time, and the Aquatabs will be taken away
- All information will be kept confidential
- Please be honest with responses
- Do you understand? Are you willing to participate?

Yes	
No	

(If no, thank and close)

Name of person interviewed:____________ __________________
Last Name **First Name(s)**

Age and gender of respondent: ______________________________

Household status: ____

1. Did you use the provided Aquatabs to treat your drinking water?

   a. If no, why not?
   b. OBSERVE: Approximately how much water is in the Jerry Can?

2. How many times in the past week have you used Aquatabs?

3. Did the Aquatabs improve the taste of the water?

4. Are the Aquatabs easy to use?

5. Have you had any problems using the Aquatabs?

6. Would you spend 3 GHC for 100 Aquatabs? (remind them that Aquatabs will continue to be provided for free for the duration of the study)

   a. If no, what do you think a fair price for 100 Aquatabs is?

7. Would you recommend the use of Aquatabs to others?

8. Has anyone in your household had diarrhea recently? Child/adult?

Thank you!

TAKE WATER SAMPLES FOR ANALYSIS IN THE LAB

Take a sample of the raw water and if they treat water take a sample of that also.

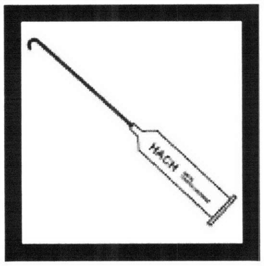
- Sample number on bottle....................................... □Raw water □Treated water

- Sample number on bottle....................................... □Raw water □Treated water

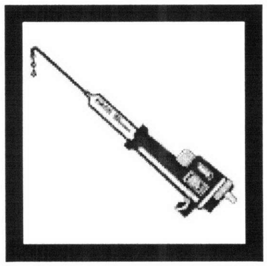
Remember to keep the samples in the cooler and do not expose the bottles to sunlight. They must be kept in a cool and dark place until analysis.

Sample time:...

Appendix E: Instructions for Hach Digital Titrator

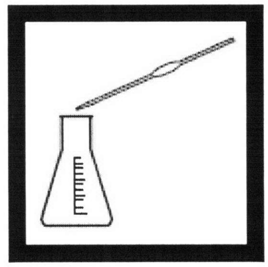


1. Insert a clean delivery tube into a 0.00564 N Ferrous Ethylenediammonium Sulfate (FEAS) Titration Cartridge. Attach the cartridge to the titrator body. See *General Description, Step-by-Step*, for assembly instructions, if necessary.

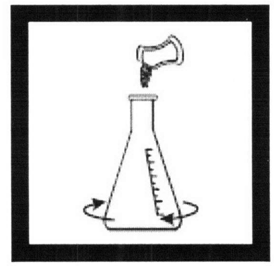


2. Turn the delivery knob to eject a few drops of titrant. Reset the counter to zero and wipe the tip.

Note: For added convenience use the TitraStir® Stir Plate. See General Description, Step 3 in Step-by-Step.



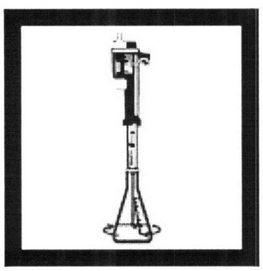
3. Pipet 25.0 mL of sample into a 50-mL Erlenmeyer flask.



4. Add the contents of a DPD Free Chlorine Powder Pillow to the sample and swirl to mix.

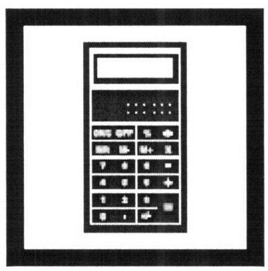
Note: Accuracy is unaffected if a small portion is undissolved.

Note: See Sampling and Storage following these steps.



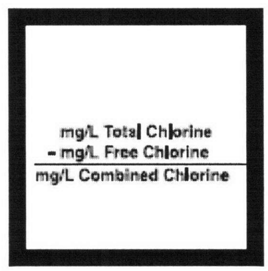
5. Place the delivery tube tip into the solution and swirl the flask while immediately titrating with FEAS to a colorless end point. Record the number of digits required.

Note: Complete the titration rapidly.



6. Calculate:

Digits Required x 0.01 = mg/L Free Chlorine

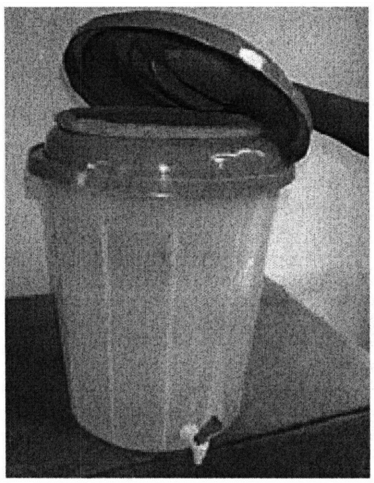


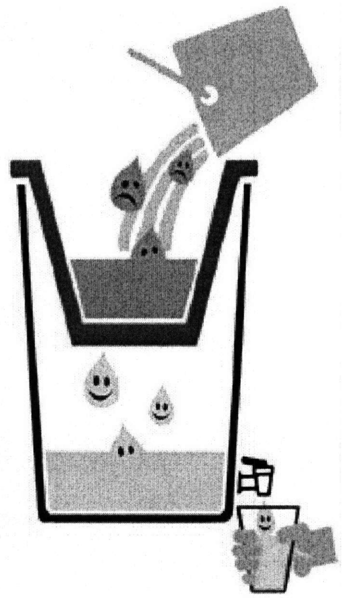
7. If total residual chlorine is desired, return to *step 3* and substitute a DPD Total Chlorine Powder Pillow in *step 4*. Wait three minutes before titrating. Continue with *step 5*. The results will be expressed as mg/L total chlorine.

Appendix F: Technical Specification Sheet for Kosim Filter

Kosim Ceramic Pot Filter

Household Water Treatment and Safe Storage (HWTS)
Pure Home Water - Product Technical Specification Sheet
by Mary Kay Jackson and Susan Murcott
October 2007





Technology

Brief description of the technology (ies), including supplies needed.

The *Kosim* filter is a ceramic pot filter manufactured in Ghana. The filter unit consists of a fired clay pot filter element, a plastic bucket storage unit with a tap and a cover. The only other supplies needed are a brush used for cleaning the filter element and soap and filtered water used to clean the storage unit.

The *Kosim* filter element is a flower pot-shaped filter measuring 31cms in diameter with a depth of 24cms. These filters are made from red clay and wood saw-dust which gets mixed, pressed in a hydraulic press and fired in a kiln. The surfaces inside and out are treated with 1 cc of 3.2% colloidal silver in 300ml of water. Volume of the filter element is 9 liters. Tests on a filter element produced in Ghana indicate that the pore size of the filter element is on the order of 40 μm (42.63 μm). [1] The filter elements are made in Ghana.

The filter element sits atop a HDPE plastic storage receptacle with a volume of approximately 30 liters. The storage receptacle has a ring that sits on top of it to hold the filter element. The filter element and storage receptacle are then covered by an HDPE lid. The storage receptacles and lids are made in Ghana.

The storage receptacle is fitted at the bottom with a plastic spigot to allow filtered water to be removed from the storage receptacle for use. The spigot, or tap, comes in two forms: a tabbed, spring loaded valve or a quarter-turn ball valve. The spigots are sourced outside Ghana from one of several suppliers.

What contaminants does it remove?

Water quality tests conducted in January 2007 assessed the effectiveness of the *Kosim* filters in the field. [2] Results for three bacterial tests and for turbidity are summarized below in Table 1 and Table 2 for traditional and modern communities. The percent removals are for paired samples from households with filters.

Table 1. Traditional Communities

Water Quality Test		Source Water	Filtered Water	Percent Removal (paired samples)
Membrane Filtration	Average *E. Coli* CFU/100mL	690 (35 samples)	2.5 (18 samples)	99.7%
	Average Total Coliform CFU/100mL	23,000 (27 samples)	170 (17 samples)	99.4%
3M Petrifilm (25 samples)	Average *E. Coli* CFU/100mL	330	0	100%
	Average Total Coliform CFU/100mL	5700	180	94%
Hydrogen Sulfide Bacteria Presence/Absence	Positive for H2S Bacteria	97% (30/31)	13% (2/16)	87% (13/15)*
	Negative for H2S Bacteria	3.2% (1/31)	88% (14/16)	
Turbidity	Average NTUs	190 (33 samples)	11 (19 samples)	92%

*Percentage of samples that tested positive in the source water and negative in the filtered water.

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[1] Mahin, Tom, "Review of Thesis "Ceramic silver impregnated pot filters for household drinking water treatment in developing countries" by Doris van Halem", Memorandum to Susan Murcott, 3 Jan. 2007.

[2] Johnson, Sophie M., et al, "Pure Home Water Ceramic Filter Project Evaluation in Northern Region, Ghana", unpublished paper submitted for presentation at the 33rd WEDC International Conference, Accra, Ghana, 2008

Table 2. Modern Communities				
Water Quality Test		**Source Water**	**Filtered Water**	**Percent Removal (paired samples)**
Membrane Filtration (6 samples)	Average *E. Coli* CFU/100mL	1.4	0.21	85%
	Average Total Coliform CFU/100mL	1500	150	90%
3M Petrifilm (7 samples)	Average *E. Coli* CFU/100mL	0	0	n/a
	Average Total Coliform CFU/100mL	440	57	78%
Hydrogen Sulfide Bacteria Presence/Absence	Positive for H2S Bacteria	29% (2/7)	0% (0/7)	100% (1/1)*
	Negative for H2S Bacteria	71% (5/7)	100% (7/7)	
Turbidity	Average NTUs	4.5 (7 samples)	1.4 (7 samples)	68%

*Percentage of samples that tested positive in the source water and negative in the filtered water.

How does it remove contaminants?

Particles, bacteria, guinea worm Cyclops and protozoa are removed by physical straining, and also by other mechanisms including sedimentation, adsorption, diffusion, inertia, and turbulence. The filter element is treated with colloidal silver which may act as a bactericide and viricide.

Capacity (flow or volume)?

The clean filter rate is 1.0 to 2.5 liters/hour. Each filter is individually tested by the manufacturer. If a filter does not meet this flow rate requirement at the time of production, it is destroyed. As a filter element is fouled, the flow rate diminishes to 0.5 liters/hour, but flow rate is recovered upon cleaning of the filter.

Replacement period?

The filter element should be replaced every three to five years. Replacement is indicated by a reduction in the recovery rate of filtration upon cleaning, or upon breakage of the filter element. The plastic buckets have a life of 10 years or more. The tap can be replaced if necessary due to breakage or fatigue failure.

Cost of technology (ies) per unit

Capital: GH¢ 15.00, including filter and appurtenances and transportation.
O&M: GH¢ 4.50p for filter element replacement, GH¢ 2.00 for tap replacement

Operation and Maintenance

1. Settle turbid water in a storage vessel before filling the ceramic pot.

2. Keep the ceramic pot filled to the top. This will improve filtration rate.

3. Clean filter with brush provided when flow rate becomes too slow.

4. Clean storage unit with soap and filtered water if necessary. Disinfect with chlorine bleach, iodine or boiling water after cleaning.

Advantages

- Easy to use
- Water tastes good.
- Keeps water fresh.
- The ceramic filter element helps keep the water cool.
- Ceramic pots are culturally acceptable, as clay pots are traditionally used for water storage
- Locally produced
- Clarifies turbid water and makes it look clear and clean
- Water is collected directly from storage receptacle for use
- Equipped with a spigot to prevent recontamination
- Ceramic pores are smaller than the size of bacteria and guinea worm cyclops
- Colloidal silver in the pores inhibits the growth of biofilms
- One-time purchase provides 3 to 5 years of drinking water for a household
- Inexpensive
- Can be used year round and at all times of day

Disadvantages

- Highly turbid water can reduce the flow rate to unacceptable levels.
- Filter element is fragile and easily broken.
- Spigots from some manufacturers are subject to fatigue failure.
- Requires regular maintenance
- Fuel required for filter element production
- Filter must be replaced over time

NGO/Distributor's Name and Contact Info

Name:	**Pure Home Water**
Contact Person:	**Mary Kay Jackson, Program Manager**
Address:	**c/o World Vision GRWP**
	PMB, Tamale, Ghana
Telephone(s):	**0246-560145**
Email:	**marykay.jackson@yahoo.com**

Appendix G: Complete Water Quality Results

Converted Water Quality Values

		1st Visit			2nd Visit			
Household #	Community	Turbidity TU	TC (CFU/100mL)	EC (CFU/100mL)	Turbidity TU	TC (CFU/100mL)	EC (CFU/100mL)	Free Cl (mg/L)
1	Kalariga	<5	200	<100	<5	<100	<100	0.43
2	Kalariga	<5	200	<100	<5	<100	<100	0.56
3	Kalariga	<5	1400	<100	<5	160	<100	0
4	Kalariga	<5	12000	<100	<5	940	<100	0
5	Kalariga	<5	500	<100	<5	<100	<100	1.01
6	Kalariga	<5	5800	<100	<5	<100	<100	>10
7	Kalariga	<5	5800	200	<5	<100	<100	0.5
8	Kalariga	<5	<100	<100	<5	<100	<100	0.97
9	Kalariga	<5	1500	<100	<5	<100	<100	0.8
10	Kalariga	<5	500	<100	<5	300	<100	0
11	Kalariga	10	11100	100	<5	42000	<100	0
12	Kalariga	<5	<100	<100	<5	<100	<100	1
13	Kalariga	10	3300	<100	<5	<100	<100	>10
14	Kalariga	<5	1600	<100	<5	400	<100	1.43
15	Kalariga	300	100	<100	<5	<100	<100	1.06
16	Kalariga	<5	300	<100	200	300	<100	0
17	Kalariga	<5	<100	<100	<5	100	<100	0
18	Kalariga	<5	<100	<100	<5	<100	<100	0.1
19	Kalariga	<5	3000	100	<5	900	<100	0
20	Kalariga	<5	2700	<100	<5	200	<100	1.28
21	Kalariga	<5	<100	<100	<5	<100	<100	0
22	Kalariga	<5	200	<100	<5	400	<100	1.26
23	Kalariga	<5	600	<100	18	600	<100	0
24	Kalariga	<5	200	<100	<5	<100	<100	0.43

Household #	Community	Turbidity	TC	EC	Turbidity	TC	EC	Free Cl
		TU	(CFU/100mL)	(CFU/100mL)	TU	(CFU/100mL)	(CFU/100mL)	(mg/L)
25	Kakpagyili	200	<100	<100	<5	<100	<100	0
26	Kakpagyili	<5	400	<100	200	<100	<100	3.4
27	Kakpagyili	<5	<100	<100	<5	<100	<100	1
28	Kakpagyili	300	7850	50	<5	<100	<100	0.8
29	Kakpagyili	<5	<100	<100	<5	100	<100	0.3
30	Kakpagyili	<5	<100	<100	<5	<100	<100	0.95
31	Kakpagyili	<5	<100	<100	150	100	<100	0
32	Kakpagyili	<5	<100	<100	<5	3600	2200	0
33	Kakpagyili	<5	<100	<100	<5	<100	<100	0.8
34	Kakpagyili	<5	<100	<100	<5	<100	<100	0.25
35	Kakpagyili	<5	3200	<100	<5	400	<100	0
36	Kakpagyili	<5	<100	<100	<5	<100	<100	1.2
37	Kakpagyili	<5	500	200	<5	<100	<100	2.4
38	Kakpagyili	<5	<100	<100	<5	<100	<100	1.51
39	Kakpagyili	<5	400	<100	<5	<100	<100	1.49
40	Kakpagyili	<5	400	<100	<5	<100	<100	0
41	Kakpagyili	<5	400	100	<5	4100	<100	0
42	Kakpagyili	<5	<100	<100	<5	<100	<100	1.73
43	Kakpagyili	<5	30000	<100	10	14000	<100	0
44	Kakpagyili	<5	1000	<100	<5	<100	<100	0.83
45	Kakpagyili	<5	<100	<100	300	1750	<100	0
46	Kakpagyili	<5	<100	<100	<5	<100	<100	1
47	Kakpagyili	<5	<100	<100	200	4200	<100	0.18
48	Kakpagyili	<5	<100	<100	<5	<100	<100	0.8
49	Kakpagyili	<5	300	<100	<5	<100	<100	1.2
50	Kakpagyili	<5	<100	<100	<5	<100	<100	>10
51	Kakpagyili	<5	<100	<100	<5	<100	<100	2.02
52	Kakpagyili	<5	<100	<100	<5	<100	<100	0
53	Kakpagyili	<5	<100	<100	<5	<100	<100	2.01
54	Kakpagyili	<5	24000	<100	300	<100	<100	0
55	Kakpagyili	<5	1300	<100	<5	1400	<100	0
56	Kakpagyili	<5	200	<100	60	<100	<100	1.29
57	Kakpagyili	<5	33200	200	25	<100	<100	1.05
58	Kakpagyili	<5	<100	<100	<5	500	<100	0
59	Kakpagyili	<5	<100	<100	<5	<100	<100	0

Raw Water Quality Values

Kalariga

Household		Initial Visit				
Household Number	Name	Date of 1st Visit	Dilution Ratio	Turbidity	TC	EC
				(TU)	(CFU/mL)	(CFU/mL)
1	Dawuni	10-Jan	1-to-1	<5	2	0
1 (2nd Filter)	Dawuni (2)					
2	Katumi	10-Jan	1-to-1	<5	2	0
3	Afishetu	10-Jan	1-to-1	<5	14	0
4	Azaratu	10-Jan	1-to-1	<5	120	0
5	Sanatu	10-Jan	1-to-1	<5	5	0
5 (Pre-Treatment)	Sanatu	10-Jan	1-to-1	400	60	2
5 (Pre-Treatment)	Sanatu	10-Jan	1-to-10	400	25	1
5 (Pre-Treatment)	Sanatu	10-Jan	1-to-100	400	2	0
6	Richia	10-Jan	1-to-1	<5	58	0
7	Ssuhini	10-Jan	1-to-1	<5	56	2
8	Safura	10-Jan	1-to-1	<5	0	0
1	Ayishetu	13-Jan	1-to-1	<5	15	0
2	Laabi	13-Jan	1-to-1	<5	5	0
3	Sana	13-Jan	1-to-1	10	110	1
4	Malia	13-Jan	1-to-1	<5	0	0
5	Sanatu	13-Jan	1-to-1	10	33	0
6	Zenabu	13-Jan	1-to-1	<5	16	0
7	Zenabu	13-Jan	1-to-1	300	1	0
8	Mariama	13-Jan	1-to-1	<5	3	0
9	Salifu	13-Jan	1-to-1	<5	0	0
10	Mapa(ow)	13-Jan	1-to-1	<5	0	0
11	Adeshetu	13-Jan	1-to-1	<5	29	1
12	Yapa(ow)	14-Jan	1-to-1	<5	27	0
12 (Pre-Treatment)	Yapa(ow)	14-Jan	1-to-1	150	49	1
13	Zenabu	18-Jan	1-to-1	<5	0	0
14	Maimuna	13-Jan	1-to-1	<5	2	0
15	Hawa	15-Jan	1-to-1	<5	6	0

Household		Second Visit				
Household Number	Name	Date of 2nd Visit		Turbidity	TC	EC
				(TU)	(CFU/mL)	(CFU/mL)
1	Dawuni	18-Jan	1-to-1	<5	0	0
1 (2nd Filter)	Dawuni (2)	21-Jan	1-to-1	<5	0	0
2	Katumi	18-Jan	1-to-1	<5	0	0
3	Afishetu	18-Jan	1-to-1	<5	160	0
4	Azaratu	10-Jan	1-to-1	<5	940	0
5	Sanatu	23-Jan	1-to-1	<5	0	0
5 (Pre-Treatment)	Sanatu					
5 (Pre-Treatment)	Sanatu					
5 (Pre-Treatment)	Sanatu					
6	Richia	21-Jan	1-to-1	<5	0	0
7	Ssuhini	19-Jan	1-to-1	<5	0	0
8	Safura	18-Jan	1-to-1	<5	0	0
1	Ayishetu	18-Jan	1-to-1	<5	0	0
2	Laabi	19-Jan	1-to-1	<5	3	0
3	Sana	18-Jan	1-to-1	<5	420	0
4	Malia	19-Jan	1-to-1	<5	0	0
5	Sanatu	18-Jan	1-to-1	<5	0	0
6	Zenabu	18-Jan	1-to-1	<5	4	0
7	Zenabu	18-Jan	1-to-1	<5	0	0
8	Mariama	18-Jan	1-to-1	200	3	0
9	Salifu	22-Jan	1-to-1	<5	1	0
10	Mapa(ow)	19-Jan	1-to-1	<5	0	0
11	Adeshetu	18-Jan	1-to-1	<5	9	0
12	Yapa(ow)	19-Jan	1-to-1	<5	2	0
12 (Pre-Treatment)	Yapa(ow)					
13	Zenabu	19-Jan	1-to-1	<5	0	0
14	Maimuna	19-Jan	1-to-1	<5	4	0
15	Hawa	18-Jan	1-to-1	18	6	0

Kakpagyili

Household		Initial Visit				
Household Number	Name	Date of 1st Visit	Dilution Factor	Turbidity	TC	EC
				(TU)	(CFU/mL)	(CFU/mL)
1	Azaara	12-Jan	1-to-1	200	0	0
2	Memunatu	12-Jan	1-to-1	<5	4	0
2	Memunatu					
3	Fuseina	12-Jan	1-to-1	<5	0	0
4	Adisa	16-Jan	1-to-1	300	46	1
4	Adisa	16-Jan	1-to-10	300	11	0
5	Aiddrisu	12-Jan	1-to-1	<5	0	0
6	Nafisa	12-Jan	1-to-1	<5	0	0
7	Ruhia	12-Jan	1-to-1	<5	0	0
7	Ruhia					
8	Rabi	12-Jan	1-to-1	<5	0	0
9	Asmwu	12-Jan	1-to-1	<5	0	0
10	Abdul Rauf	12-Jan	1-to-1	<5	0	0
1	Abiba	15-Jan	1-to-1	<5	32	0
2	Asibi	16-Jan	1-to-1	<5	0	0
3	Memumatu	15-Jan	1-to-1	<5	3	2
4	Sanatu	15-Jan	1-to-1	<5	0	0
5	Sanatu	15-Jan	1-to-1	<5	4	0
5 (Dugout, Stored)	Sanatu	15-Jan	1-to-10	400	8	0
6	Alhassan	15-Jan	1-to-1	<5	4	0
7	Iddrisu	16-Jan	1-to-1	<5	3	1
8	Adam	15-Jan	1-to-1	<5	0	0
9	Fusini					
10	Shefuu	15-Jan	1-to-1	<5	10	0
11	Abukari	15-Jan	1-to-1	<5	0	0
11	Abukari					
12	Bibata	15-Jan	1-to-1	<5	0	0
13	Zachina	15-Jan	1-to-1	<5	0	0
13	Zachina					
14	Mariama	15-Jan	1-to-1	<5	0	0
14 (Piped, Stored)	Mariama	15-Jan	1-to-10	<5	2	0
15	Rachia	16-Jan	1-to-1	<5	3	0
16	Salanatu	16-Jan	1-to-1	<5	0	0
16 (Dugout, Stored)	Salanatu	16-Jan	1-to-10	<5	4	0
17	Fatimata	16-Jan	1-to-1	<5	0	0
18	Maria	16-Jan	1-to-1	<5	0	0
18 (Piped, Tank)	Maria	16-Jan	1-to-10	<5	12	0
19	Bibata	16-Jan	1-to-1	<5	0	0
20	Mariamu	16-Jan	1-to-1	<5	240	0
20	Mariamu					
21	Latifa	21-Jan	1-to-1	<5	13	0
21	Latifa					
22	Falira	16-Jan	1-to-1	<5	2	0
22	Falira					
23	Matim	16-Jan	1-to-1	<5	330	2
24	Sabratu	21-Jan	1-to-1	<5	0	0
25	Rahima	21-Jan	1-to-1	<5	0	0

Household		Second Visit				
Household Number	Name	Date of 2nd Visit	Dilution Factor	Turbidity	TC	EC
				(TU)	(CFU/mL)	(CFU/mL)
1	Azaara	21-Jan	1-to-1	<5	0	0
2	Memunatu	21-Jan	1-to-1	200	0	0
2	Memunatu	21-Jan	1-to-10	200	0	0
3	Fuseina	21-Jan	1-to-1	<5	0	0
4	Adisa	21-Jan	1-to-1	<5	0	0
4	Adisa					
5	Aiddrisu	21-Jan	1-to-1	<5	1	0
6	Nafisa	21-Jan	1-to-1	<5	0	0
7	Ruhia	21-Jan	1-to-1	150	2	0
7	Ruhia	21-Jan	1-to-10	150	0	0
8	Rabi	21-Jan	1-to-1	<5	14	22
9	Asmwu	21-Jan	1-to-1	<5	0	0
10	Abdul Rauf	21-Jan	1-to-1	<5	0	0
1	Abiba	21-Jan	1-to-1	<5	4	0
2	Asibi	21-Jan	1-to-1	<5	0	0
3	Memumatu	21-Jan	1-to-1	<5	0	0
4	Sanatu	23-Jan	1-to-1	<5	0	0
5	Sanatu	22-Jan	1-to-1	<5	0	0
5 (Dugout, Stored)	Sanatu					
6	Alhassan	21-Jan	1-to-1	<5	0	0
7	Iddrisu	22-Jan	1-to-1	<5	41	0
8	Adam	22-Jan	1-to-1	<5	0	0
9	Fusini	22-Jan	1-to-1	10	140	0
10	Shefuu	23-Jan	1-to-1	<5	0	0
11	Abukari	22-Jan	1-to-1	300	15	0
11	Abukari	22-Jan	1-to-10	300	2	0
12	Bibata	21-Jan	1-to-1	<5	0	0
13	Zachina	22-Jan	1-to-1	200	54	0
13	Zachina	22-Jan	1-to-10	200	3	0
14	Mariama	21-Jan	1-to-1	<5	0	0
14 (Piped, Stored)	Mariama					
15	Rachia	21-Jan	1-to-1	<5	0	0
16	Salanatu	21-Jan	1-to-1	<5	0	0
16 (Dugout, Stored)	Salanatu					
17	Fatimata	22-Jan	1-to-1	<5	0	0
18	Maria					
18 (Piped, Tank)	Maria	23-Jan	1-to-1	<5	0	0
19	Bibata	22-Jan	1-to-1	<5	0	0
20	Mariamu	21-Jan	1-to-1	300	0	0
20	Mariamu	21-Jan	1-to-10	300	0	0
21	Latifa	21-Jan	1-to-1	<5	23	0
21	Latifa	21-Jan	1-to-1	<5	5	0
22	Falira	22-Jan	1-to-1	60	0	0
22	Falira	22-Jan	1-to-10	60	0	0
23	Matim	22-Jan	1-to-1	25	0	0
24	Sabratu	23-Jan	1-to-1	<5	5	0
25	Rahima	22-Jan	1-to-1	<5	0	0

Aluminum Sulfate (Alum) Coagulation[6]

Household Water Treatment and Safe Storage (HWTS)
Product and Implementation Fact Sheet

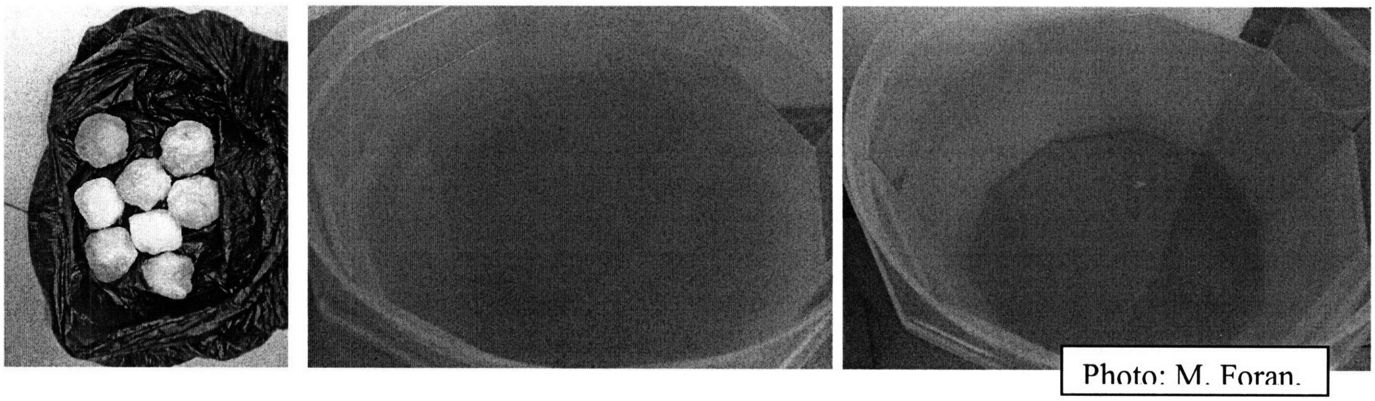

Fig. 1 alum balls; Fig 2 turbid surface water from "dugout"; Fig. 3 after alum coagulant.

Technology Description

When alum is added to turbid water and gently agitated, it causes particles to aggregate and settle by gravity. The process is called coagulation/precipitation. Coagulation /precipitation is a widely applied process in urban water treatment plants around the world. It is also sometimes applied at a household scale, for example, in India, China and Southeast Asia, alum coagulation has been practiced for hundreds of years. A coagulant is a chemical which, when added to water, enables small particles to aggregate into larger flocs. Aluminum sulfate $(Al_2 (SO_4)_3) \cdot H_2O$ is the perhaps the most commonly used coagulant/precipitant worldwide.

Alum is a local solution applied to mitigate the problem of high turbidity surface waters in Northern Ghana. It is unknown how long alum has been employed as an indigenous water treatment practice in Ghana; however, alum is applied as part of a treatment process in urban treatment plants in Ghana. Alum is imported into Ghana. For example, a dry, granular alum product from Kemira A.B. in Finland is distributed by Dakgyeis in Accra, perhaps because of consistent quality and quantity concerns.

Supplies needed to treat water via coagulation include the coagulant itself and an appropriately sized vessel. Alum balls (see photo above), which is a commercial alum product pressed into a 2.5 cm diameter ball, are sold individually or in packets in the local markets and are vended in villages and urban centers in Ghana. Local women say

[6] Fact Sheet prepared by Susan Murcott with assistance from Kellye Doyle, Melinda Foran, and Jennifer Christian-Murtie

that they only apply alum in the dry season when the surface water sources are drying out and concentrating the turbidity.

What contaminants does it remove (based on manufacturer's claims)?

Suspended and colloidal particles, which can be organic or inorganic. Some microbial contamination is also removed, because microbes often attach to particles, but coagulation does not disinfect the water, only coagulation is a step towards cleaner water. In addition, alum, as well as other metal salts such as ferric salts, remove metals via the process known as precipitation – see below. Natural polymers do coagulate and remove particles of turbidity and some associated microbes, but don't precipitate metals.

How does it remove contaminants?

Turbid water is comprised of suspended and colloidal particles which can agglomerate into larger particles via coagulation/precipitation. These particles can settle by gravity and/or be removed by a filter.

Coagulation is the electro-chemical process of bringing together small particles into larger particles. Flocculation, a transport process, is the aggregation of these coagulated particles to form larger groups of particles called flocs. Sometimes these two terms, coagulation and flocculation, are used inter-changeably. Precipitation refers to the chemical reaction that converts a soluble substance into a solid. For example, when aluminum sulfate is added to water containing calcium and magnesium alkalinity, a precipitate of aluminum hydroxide will form according to the following chemical reaction:

$$3Ca(HCO_3)_2 + Al_2(SO_4)_3 \cdot 18\ H2O \leftrightarrow 2Al(OH)_3 + 3CaSO_2 + 6CO_2 + 18\ H_2O$$

[Calcium bi-carbonate + Alum] ↔ [aluminum hydroxide + calcium sulfate + carbon dioxide + water]

Capacity (flow rate and/or batch volume) In Ghana, the typical water collection vessel is about 40 L and that is a standard volume for manual treatment. However, dosing of alum is imprecise, and most users apply the coagulant by intuition, having learned the practice from their mothers or other older women.

Cost of Technology per Unit

> **Capital:** Assuming the user has at least one water collection vessel, such as the 40+L metal vessel previously described, as well as and a cloth filter (which are widely and freely disseminated in Ghana), then there is no capital cost for this method of treatment.

O&M: US$ 0.01 to $0.03 per ball. (For cost calculations, we assume that one ball can treat 2 x 40L of highly turbid water).

The pricing in the Tamale market is as follows:

- Distributor buys the large 50 kg bags for anywhere between 18 and 20 cedis[7] ($19– $22) and then she may sell the entire bag to someone for 22 to 24 cedis($24 - $26), depending on what she paid for it.
- She will sell 1 alum ball for 20 pesewas (0.02 cedis) ($0.02)
- She usually sells 7 alum balls at a time for 0.10 cedi (($0.11), a discounted rate of about 14 pesewas ($0.015) per ball
- The stalls in the market usually buy 7 alum balls from her at 0.10 cedis ($0.11) and then sell them to other people one ball at a time for 20 pesewas ($0.02), interestingly, the same rate as the distributor.

Effective Household Water Management with this Product

Operation

The method, as demonstrated by a woman from Savelugu, is that after she collects water for a source (Step 1), she takes one alum ball and swirls it by hand in her 40L metal containers of source water. Depending on how turbid the water is, she swirls for several minutes until it "looks right." Then she waits while the flocs form into larger agglomerations, before settling by gravity to the bottom of the bucket. Clear water is decanted from the top. The indigenous procedure is effective, but it is neither hygienic nor is it standardized.

[7] Exchange Rate: GHS 1.00 = US$ 1.08 (November 14 2007).


Fig. 4. Step 1: Collect water from turbid source, a dugout in Savelugu , Ghana.

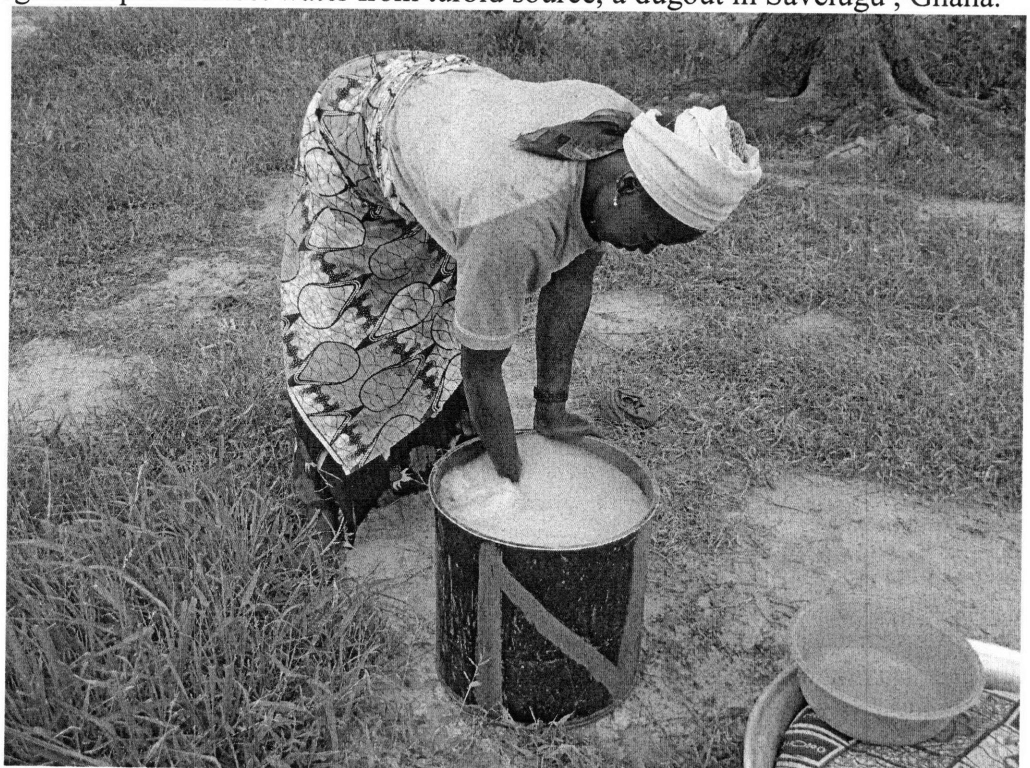
Fig. 5. Step 2: Manual coagulation with one alum ball

Fig. 6. Step 3: Let water coagulate and allow the flocs to settle.

A more standardized procedure to treat water with alum at the household level is as follows:

Two clean standard-sized buckets should be available at the outset. The alum ball is added to a known quality of water (e.g. 40 liters) and rapidly mixed manually with a large, clean spoon (users should be dissuaded from using one's hand/arm), then the liquid is allowed to coagulate and settle for 5 minutes. Next, the coagulated water is decanted by pouring it into a second safe storage container covered by a cloth filter to capture and prevent the floc/sludge from going into the clean water. The process is visually impressive, and the settling of the flocs to the bottom is the indication that the water is safer - with reductions of both turbidity and microbes, but the water has not been completely disinfected by this method.

Maintenance/Cleaning

Storage vessels may build up sludge from the flocs that form and settle subsequent to the treatment process. These vessels need to be regularly cleaned with soap, clean and/or boiled water and the sludge discarded.

Replacement period

Alum is a consumable, as opposed to a durable, product that is replaced after each use or several uses. Manual coagulation with alum balls, as practiced and observed in parts of rural Ghana with dugout, river and other highly turbid water, requires about one alum ball per treatment for one standard 40 L metal water collection vessel. If used conservatively or if the water is not excessively turbid, one alum ball can last for several treatments of this volume of water.

Water Quality Monitoring

Turbidity monitoring of a subset of alum coagulated household waters should occur on an annual basis using a turbidity tube (DelAgua Water Testing Ltd Wiltshire, UK) or a turbidimeter.

Water Quality – Independent Testing Results

Household-scale alum coagulation of highly turbid source water from Northern Region, Ghana was compared to solar disinfection in plastic bags (SolAgua) in a Master thesis study (Foran, 2007). *E.coli* removal efficiencies for alum alone were practically the same as with alum combined with SolAgua disinfection.

Table 1: *E.coli* concentration and percent removal of alum coagulation alone compared to alum coagulation + solar disinfection in Northern Region, Ghana

Sample	**Raw Water *E. coli* [CFU per 100mL]**	**Post-Alum *E.coli* [CFU per 100mL]**	**Post-Alum + SolAgua E.coli[CFU per 100mL]**	**% E.coli Removal Post-Alum**	**% E. coli Removal Post-Alum + SolAgua**
Ghanasco Muali Dam, TD	6,733	6	0	99.9%	100.0%
Kaleriga Dam, TD	14,300	30	0	99.8%	100.0%
Bipelar Dam, TD	21,667	15	1	99.9%	100.0%
St. Mary's Dam*, TD	53,830	14	2	100.0%	100.0%
Dungu Dam*,TD	4,620	108	6	97.7%	99.9%
Libga Dam 1*, SD	500	3	0	99.4%	100.0%
Bunglung Dam, SD	5,150	1	0	100.0%	100.0%
Diare Dam, SD	3,417	3	0	99.9%	100.0%
Libga Dam 2, SD	1,417	0	0	100.0%	100.0%
Gbanyami Dam, TD	19,333	0	0	100.0%	100.0%
Vitting Dam, TD	14,167	0	0	100.0%	100.0%
Average Removal Efficacy				**99.7%**	**100.0%**

There was a significant improvement in *E. coli* concentrations after alum administration and SolAgua disinfection (p=0.009). *E. coli* reduction post-alum with SolAgua was high (>99%) in nine samples tested. On average, the removal efficacy of *E. coli* was 99.7% for alum coagulation alone and 100% for alum coagulation + SolAgua treatment. The Wilcoxon Rank-Sum test was performed using this data and there was no significant difference in the removal efficacy of *E. coli* using alum alone or alum combined with SolAgua disinfection (p=0.153), likely due to the small sample size.

Health Impact Studies

N/A

Advantages

- An indigenous practice in certain parts of the world
- Inexpensive;
- Can remove some or all of the turbidity; depending on various key variables affecting successful coagulation including coagulant type and quality, dose, mixing time and speed, settling time, water quality characteristics and more.
- Metal salt coagulants such as alum precipitate metals and remove some organic chemicals
- Only requires two containers (one for coagulation, the other for decanting) and a cloth filter to catch the flocs when pouring off the supernatant into the 2nd containers
- Visually, one can see the water become cleaner on account of the treatment. This can be convincing to users of the efficacy of the product.

Disadvantages

- Removes some, but not all, microbial contamination;
- Not proven to reduce diarrheal diseases;
- Some users find the process of stirring, pouring and waiting tedious.

Name of Implementing Organization

Finland: Kemira A.B.
Ghana: Dakgyeis Water Chemicals is one distributor of alum products for the water treatment plant market.

Type of Implementation Organization

For profit

Sale of alum balls is a "bottom of the pyramid," private sector business in Ghana. Certain vendors in the downtown marketplace in Ghana are the core distributors, to other shops downtown, and to retailers. Typical street vendors of alum balls are young girls who head-load basins with their wares, which might be sachet water, juices and other small consumer products, including alum balls. However, alum balls are not an everyday product – the supply is not constant and you have to know where to get it. However, because alum is also used for fixing dyes in the cottage industry of cloth dying, with a little effort, alum can be obtained from multiple sources in the Northern Region.

Location and Extent of Implementation / Sales

When a number of women collecting water at Dungu Dam near Sagnirigu were asked whether they had heard of alum, everyone had. Then when asked if they ever applied it, some indicated use of alum balls in the dry season. It was very hard to judge the extent of implementation; however, one indication that household-scale alum coagulation was somewhat widespread was that it could be bought in the markets fairly readily in Ghana.

References

Foran, Melinda. 2007. "An Analysis of the Time to Disinfection and the Source Water and Environmental Challenges to Implementing a Solar Disinfection Technology (SolAgua)" Masters Thesis, Department of Population and International Health, Harvard School of Public Health, Boston, Massachusetts, May, 2007

Contact

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