INDEPENDENT EVALUATION OF THE BIOSAND WATER FILTER IN RURAL CAMBODIA: SUSTAINABILITY, HEALTH IMPACT AND WATER QUALITY IMPROVEMENT

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The United Nation's 7th Millennium Development Goal aims to reduce by half the number of people without sustainable access to safe drinking water. Safe water is critical to preventing diarrheal disease, which kills 2 million children annually. A promising household water treatment technology is the BioSand water filter (BSF), an intermittent slow sand filter that is locally made in Cambodia and several other developing countries. The BSF however, lacks adequate characterization and rigorous epidemiological evidence on its performance.

The purpose of this research was to assess: (1) the factors associated with filter use and disuse by using a cross-sectional survey (2), the microbiological effectiveness of the BioSand filters still being used by reduced *E. coli*, and (3), the health impact of the BioSand filters as determined by a longitudinal, prospective cohort study in which diarrheal disease prevalence was measured among people in filter (intervention) households versus people in matched non-filter, control households.

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Introduction

Poverty, Health and Water

The 7th United Nations Millennium Development Goal aims to reduce poverty and hunger by ensuring environmental sustainability which also includes the provision of access to drinking water and basic sanitation. Access to safe water is not only a basic need for life but also arguably a human right. It is estimated that over a billion people worldwide, nearly 20% of the worlds total population, do not have access to safe drinking water (WHO/WPRO). The global burden of disease is largely attributable to a lack of water, sanitation and hygiene. In developing countries, 85-90% of diarrheal disease is due to unsafe water, hygiene and sanitation (WHO/WPRO). Pruss et al.(2002) estimate that 4.0% of all deaths globally are attributable to unsafe water and sanitation. An estimated 4 billion cases of diarrhea annually represented 5.7% of the global disease burden in 2000(WHO 2002). Infectious diarrhea is the largest water-related contributor to the global disease burden and it is carried mostly by women and children in less developed countries. Of the 1.8 million people that die every year from diarrheal disease, 90% are children under 5(WHO/WPRO).

Consuming unsafe water causes gastro-intestinal illnesses that lead to diarrhea, dehydration, and malnutrition especially for children in developing countries. Children are more vulnerable because they have undeveloped digestive and immune systems which makes them more susceptible to the effects of diarrhea. Children experience an average of three or more episodes of diarrheal disease each year (Kosek, Bern & Guerrant), accounting for a large proportion of the estimated 4 billion cases of diarrheal disease estimated each year. Diarrhea and other adverse health effects are related to viral, bacterial and parasitic microbes which are transmitted through contaminated water, food, hands, fomites and other vector borne routes. It is known that organisms that cause diarrhea are associated with fecal matter and transmitted through the fecal oral route of infection (Curtis et al., 2003).

Household Water Treatment

The cost of providing necessary infrastructure for safe piped water is often prohibitive for people and communities in less developed countries. Recently, studies have shown that an effective intervention for provision of safe water to consumers is through point of use (POU) household water treatment and safe storage (HWTS). A recent review estimates that 94% of diarrheal diseases are attributable to environmental causes which suggests that the burden of diarrhea can be decreased by water, sanitation, and hygiene interventions (Pruss-Ustun & Corvalan, 2006). Research has shown that POU technologies can improve water quality and reduce diarrheal disease by an average of 40% (95% confidence interval of 19% - 54%) in users versus non users (Fewtrell et al., 2005). For households and communities that do not have access to conventional treatment systems, point of use treatment can provide access to safe water.

Household water treatment is not a novel practice and can be effective for households and communities without access to a conventional community water supply system. The extent to which improving drinking water at the household level in reducing diarrheal disease depends on technology-related as well as demographic factors. Reductions in household diarrheal diseases of 6-90% have been observed, depending on the technology, and the exposed population and local conditions (WHO, 2007).

There are several different household water treatment technologies that are used in many different parts of the world. These technologies are used to improve the microbial quality of household water and reduce waterborne disease and include a number of physical and chemical treatment methods (WHO 2007). The physical and chemical treatment methods include, boiling, heating (fuel and solar), settling, filtering, exposing to the UV radiation of the sunlight (SODIS, solar disinfection using clear bottles by the combined action of UV radiation and heat), and UV disinfection with lamps. Physical treatment removes particles (turbidity) and microbes, or inactivates microbes in household water, specifically indicator organisms. Boiling, solar disinfection, UV disinfection with lamps, chlorination and the combined treatments of chemical coagulation-filtration and chlorination are able to reduce bacteria, viruses, and in some cases protozoans (WHO 2007). Chemical methods for treating household water include coagulation-flocculation and precipitation, adsorption, ion exchange and chemical disinfection with germicidal agents (primarily chlorine) (WHO 2007), such as the PUR sachet developed by Proctor and Gamble.

The efficacy of some treatment methods to physically remove particles (turbidity), and microbes or to inactivate microbes in household water has been documented, primarily for indicator bacteria, and some have been evaluated for reductions of viruses and protozoans as well (WHO, 2007). Besides being gauged for the ability to reduce pathogens, household water treatment also needs to be accessible, simple and inexpensive to operate in order for people to effectively treat and store water in a household setting.

Study Background and Rationale

The BioSand Water filter is an emerging point of use water treatment technology that is being implemented and promoted internationally. There is a lack of independent evaluations and independent appraisals of the BSF in the field to assess sustainability, water quality and health impact. Laboratory and field studies conducted by Palmateer et al. (1999) and Stauber et al., (2006) examined different parameters including *E. coli* reductions achieved by the BSF. Two laboratory studies show mean *E. coli* reductions of 94% and reductions were shown to improve over the period of filter use, reaching a maximum of 2 $\log_{10}$ or 99% reduction. Fecal contamination was reduced by approximately 90% for viruses, 90-99% for bacteria and > 99.9% for protozoan parasites (Stauber et al., 2006).

In addition to the limited performance data on the ability of household scale BSF to reduce microbes and other contaminants from water in the laboratory, the BSF still lacks rigorous scientific evidence of its ability to reduce diarrheal illness and other potential health impacts in the field. Currently, Cambodia is the country with the largest number of BSFs in the world. BSFs are being widely promoted in Cambodia and elsewhere despite only limited field data. Although there have been internal evaluations conducted by non governmental organizations, no independent evaluations using scientifically rigorous methods have quantified the performance of these filters to improve water quality and reduce waterborne diarrheal disease in Cambodia. The effectiveness and long term use of BSFs over time have not been well studied and further investigation of sustainability and effectiveness is imperative before further implementation and scaling up of projects goes forward or is promoted in developing countries. The need for such field performance studies of the BSF is the basis of this report.

Study Overview and Objectives

This study is an independent, follow-up assessment of two large-scale implementation programs of the BioSand water filter in Cambodia. The study is an epidemiological and microbiological assessment of the BSFs' health impact and water quality performance since the introduction of the BSF into Cambodian households since 2001.

Internal assessments and program monitoring efforts were previously conducted by various partners who have implemented BioSand filter and related water, sanitation and health programs in Cambodia. As these reports were internal in nature and focused on individual NGO implementation efforts they are not considered independent and objective assessments of the sustainability and performance of BioSand filters or their implementation programs. However, there are a number of documents which should be referenced on the progress of BSF program development in Cambodia, primarily that by Kaiser et al., 2001, and Manz and Buzunis, 1993. Findings from the Manz and Buzunis study show a reduction of 99.1% of fecal coliform indicator organisms from BSFs installed in Nicaragua and up to 100% when the biofilm had developed. The study conducted in six different countries conducted by Kaiser et al., showed an average of 93% removal of fecal coliforms.

This study assesses the water quality and health impacts of the BSF interventions by Hagar and CGA who were sponsored and supported by Samaritan's Purse, and provides information on the sustainability and effective performance of the filters and their implementation programs by measuring the following parameters and indicators:

i. the continued use of previously installed filters over time, expressed as the proportion of initial household filters still in use since introduction, and the identification of factors potentially associated with filter uptake and long term use;

ii. the microbiological effectiveness in situ of the filters still being used, as determined by computing log_{10} (and percent) reduction values of the WHO-recommended fecal indicator bacterium, *E. coli*; and

iii. the health impacts of the filters as determined by a prospective cohort study in which diarrheal disease prevalence is measured among people in filter (intervention) households versus people in matched non-filter, control households.

This study also gathered data intended to elucidate factors influencing implementation success and identifying the challenges and key issues relating to sustainability of BSF filters in Cambodia households and villages. The study was carried out in two parts:

(i), an initial cross sectional survey of households previously given filters to determine which ones were still using the filter in order to compute filter uptake and use rates and associated factors influencing use or disuse; and

(ii), a longitudinal prospective cohort study of over 100 households still using the filter (intervention) and over 100 matched non filter households (controls). In these households the goals were to determine the impact of the filter on water quality, based on microbiological and turbidity reduction effectiveness and measure the health impacts of the filters in household use by comparing diarrheal disease rates in filter and matched non-filter households.

The BioSand Filter

One of the most promising POU filtration technologies for the developing world context is the BioSand Water Filter (BSF), a household-scale, intermittently operated slow sand filter invented in its current form by Dr. David Manz in the early 1990s. The concrete chamber household-scale BSF has been patented in Canada and the United States and was developed for humanitarian purposes (Manz 2007). Currently, there are over 200,000 BSFs installed and implemented worldwide by several non-governmental organizations (Manz 2007). Filters are intended to provide households in disadvantaged, underserved or impoverished communities with access to safe drinking water. Supplementary programming related to implementing BSFs in households is directed at other development targets complimentary to water and sanitation activities, such as improved hygiene, and maternal and child health, and increased availability of time previously devoted to gathering water for other household and extra-household activities, including employment and education. A concrete BSF has the capacity to provide drinking water for a household or communal unit on a demand basis by the process of intermittent slow sand filtration.

The BSF is specifically adapted for use in the home. It operates with intermittent, by on-demand flow of water created by pouring raw feed water into the top of the filter unit for gravity flow through the filter bed and exit of the filtered water from a bottom outlet pipe that is directed upwards as a standpipe so that the filtrate exits 5-6 cm above the surface of the filter sand bed (Figure 1), The most widely used version of the BSF is a concrete container approximately 0.9 meters tall and 0.3 meters square, filled with a layer of fine sand below which are layers of supporting gravel.. The shallow water layer above the sand bed allows a bioactive layer or "schmutzdecke" to grow on top of the sand, which contributes to the filtration that reduces disease-causing organisms and other dissolved and particulate impurities in the applied water. A rectangular plate with small holes (diffuser plate) in it is placed in the filter several cm above the top of the sand bed and standing water to prevent disruption of the bioactive layer when water is added to the top of the filter. To operate the system, users pour water into the BSF, and collect finished water from the outlet pipe in a bucket, bottle or other safe storage container.

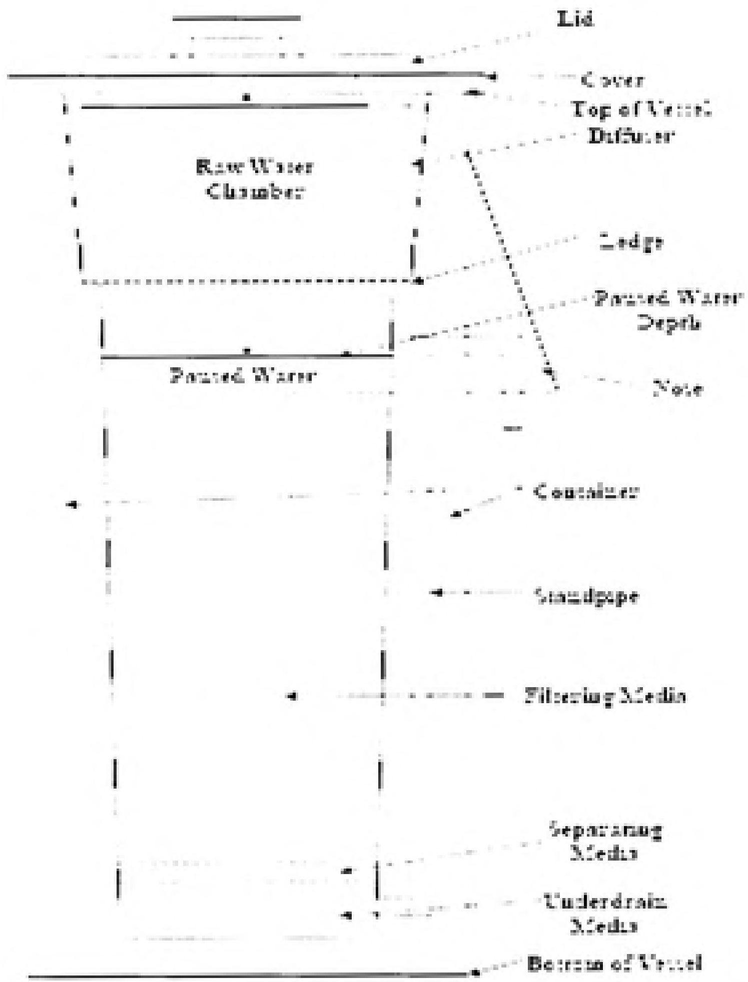


Figure 1 Concrete BSF cross-sectional diagram (Manz)

Although the ability of traditional slow sand filters to reduce pathogens in water is well-documented, the effectiveness of intermittent slow sand filtration by the BSF unit is somewhat uncertain because it has a modified design and different operating properties. Traditional slow sand filters are operated continuously at constant head and a low flow rate of about 1 liter per minute per meter square of filter surface area, and the upper layer (few centimeters) of sand is periodically replaced with clean sand when the flow rate declines and there is an excessive accumulation of impurities at the sand surface. However, the BSF is operated intermittently, head and flow rate vary and the upper few centimeters of sand containing the schmutzdecke are not replaced but rather cleaned periodically by manual agitation ("harrowing") and decanting of the released contaminants and excess biological growth (Elliott, 2006).

Limited evidence of the BioSand filter's ability to reduce waterborne microbes in lab studies or field use has appeared in the peer-reviewed literature. Palmateer et al. (1999) documented > 99% removal of *Giardia* cysts and *Cryptosporidium* oocysts and 65-90% reductions of indigenous fecal coliform bacteria. Buzunis (1995) reported typical fecal coliform reductions of about 96% in lab studies at the University of Calgary. As *E. coli* is the recommended fecal bacterial indicator of drinking water quality and is less prone to variability and uncertainty caused by the diversity of fecal coliform bacteria, studies on its reduction by the BSF are much needed. In household scale BioSand filters with a plastic housing, *E. coli* reductions from daily doses of 40 liters of water averaged 94% over operating periods of several weeks that included initial dosing of filters lacking a schmutzdecke and reached nearly 99% once the filter ripened (matured) and the schmutzdecke had developed (Stauber et al., 2006)

Cambodia Health Indicators

Cambodia's population is 13 million, based on the 2004 intercensal survey (WHO 2004b). The total fertility rate is 3.3 (2004) and the annual population growth rate from 1998 to 2004 was 1.8% and the birth rate was 25 per 1000. Life expectancy for males is 56 years and for females, 60 years according to 2001 data. The median age is just under 20 years, with the proportion aged 0-24 being twice that of those aged 25-50. Eighty-four per cent of the population lives in rural areas, but there is a shift towards urban areas in recent years, especially among young people (WHO 2004b).

Child mortality indicators in Cambodia are among the poorest in the world. The infant mortality rate and under-five mortality rate per 1000 live births (Under 5 Mortality Rate or U5MR) were reported to be 95 and 124, respectively in 2000 (WHO). The reported prevalence of diarrhea for the children under-five group was 19 % (NIS 2000) in Cambodia in 2000 for a two week recall period. Health indicators also show that diarrhea was a leading cause of mortality and morbidity for Cambodian children (WHO/WPRO Cambodia Environmental Health Country Profile, 2004). In 2000, diarrhea and dysentery cases across all age groups were reported to be 383,118 and 3622 respectively (WHO/WPRO Cambodia Environmental Health Country Profile, 2004). Communicable diseases including diarrhea, typhoid fever, hepatitis and cholera have strong associations with drinking water quality and can be greatly reduced and even eliminated with adequate water supply and sanitation. Access to safe water for rural Cambodians remains a problem for households throughout the country. Only 31% of the total population has access to safe water, 54% in the urban areas and 27% in rural areas (WHO/WPRO Cambodia Environmental Health Country Profile, 2004). Due to improved case management in families or communities or through health centers for diarrheal episodes in children, case-fatality rates have declined steadily and contributed to the reductions in U5MR. The decrease in case-fatality has been accompanied by a downward trend in the burden of disease due to diarrhea. However, the prevalence of pathogens in the immediate human environment and the resulting number of diarrheal episodes per year are not decreasing through therapeutic or preventive measures. Therefore, there still remain considerable adverse health risks from these exposures to the agents through contaminated environmental media such as water. Diarrhea and other infectious diseases also directly affect the nutritional status of children and contribute to developmental stunting (WHO/WPRO).

Cambodia Household Water Treatment and Safe Storage

Drinking water supply is still inadequate in most provinces of Cambodia, in terms of water quantity, quality and access. Water quality problems are mainly microbiological, followed by arsenic contamination of groundwater (WHO). Among the major causes of water pollution are deforestation and erosion, industrial effluents and wastes (sanitary, hospital and household wastes), agrochemicals, mining and transboundary pollution from upstream countries, all of which decrease the carrying capacity of the environment. Cambodia's economy is agrarian based. The heavy use of agrochemicals, including pesticides, to increase yields has caused the pollution of surface and groundwater sources (WHO, 2004b).
Only 21% of the population has access to adequate excreta disposal facilities which affects the quality of surface waters (WHO/WPRO Cambodia Environmental Health Country Profile, 2004). In Cambodia, it is common practice to dispose of personal, community and industrial effluents into water bodies, often without undergoing treatment, and by discharge through inadequate or unofficial drainage systems. Wastes from hospitals, formal and

informal residential areas, and slaughterhouses are also indiscriminately discharged into water bodies. In 2003, Phnom Penh and vicinity generated between 24,322,000m^3 to 34,456,000m^3 of waste water, from houses and hospitals alone (WHO, 2004b) and discharged waste into area rivers and lakes. Surface water is often used in both wet and dry seasons as a primary source for household drinking water, as well as harvested rainwater in the wet season (July to December) in both rural and peri-urban areas. Heavy rainfall and deforestation in the Mekong Delta and river basin, the most populated region of country, has contributed to the flooding and degradation of surface water sources through a decrease in the environmental assimilative capacity, with a corresponding increase in waterborne diseases.

In addition to water-related infectious diseases, exposure to hazardous chemicals in drinking water is a serious issue in the Mekong region, some ground water sources in the country are also known to contain high levels of naturally occurring arsenic and other chemical contaminants in groundwater (Feldman et al. 2007; Polya et al. 2005). Mining operations, and discharges from industry, intensive agriculture, towns and mega-cities will often introduce additional xenobiotic and other chemical compounds into groundwater and surface water. Some compounds may lead to chronic health effects and are very difficult to remove from water (WHO). Surface water (often of poor microbiological quality) and rainwater catchment (susceptible to contamination during storage) are the principle alternatives to arsenic-contaminated groundwater (Brown et al, 2006).

The widespread lack of safe drinking water sources and the unavailability of centralized systems for delivery of safe water to households means that for the 66% of the rural population who do not have access to improved drinking water sources (NIS 2004), the options for access to safe water are limited. Household water treatment and safe storage has the potential to improve the microbial quality of water and thereby reduce adverse health effects by preventing waterborne pathogen exposures leading to water-borne illnesses. Cambodia has become a major locus for household water treatment research, demonstration and implementation because of the lack of safe water, the limited prospects for centralized systems in rural areas and the motivation and expertise of in-country specialists (Brown et al., 2006). An estimated 200,000 people (1.5% of Cambodia) already use some form of filtration (BioSand or ceramic water purifiers) or chemical treatment at the household level (Brown et al., 2006). There are also other treatment methods widely used at the household level in Cambodia, such as boiling, cloth filters, settling and chemical coagulants.

For the purpose of this study, the filters and the households that were included in this project were selected from the approximately 19,557 BSF's introduced into households in Kompong Thom, Kratie, and Svey Rieng province by Hagar and Samaritan's Purse Canada, with funding from CIDA (Canadian International Development Agency) beginning in 2001. Also included in the study were the filters and their households of an implementation program by the NGO (non-governmental organization) formerly known as AOG (Assembly of God) and now called Cambodia Global Action (CGA). Since 2002, this organization introduced over 2668 BSFs in communities in Kandal and Kompong Speu provinces, where they have also implemented CHE (Community Health Education) programs.

Earlier pilot projects were responsible for the dissemination of several hundred BioSand filters, however those filters were not included in the production and distribution cycle under a project supported by CIDA (Canadian International Development Agency) funding and therefore were excluded from this study. Food for the Hungry (FHI), Assembly of Christ

(AOC), World Vision (WV), and Christian and Missionary Alliance (CAMA) also distributed hundreds of filters within the past 7 years, but their filters will not be included in this study.

Chapter II

Methods and Materials

Cross Sectional Study Design and Methods

The cross sectional study examined the adoption of the BioSand water filters in households that met eligibility criteria described below and consented to participate. Households that received a filter and could be located were included in this assessment. These households were part of large-scale BSF implementation programs and after obtaining the informed consent form from the head of household (typically the primary caregiver for the children, usually an adult female) the field team determined if the filter was in current use. Filters were considered in use if: (1) the filter was in good working order by visual inspection (all the filter parts were intact and functional) and (2), the filter was reported to be used atleast once within the past week.

The field team also gathered data on post implementation filter use and practices as well as user acceptance of the BSF from the time of installation to the time of this study. Usage rates were taken as measures of sustainability of the technology in the households. Households were administered surveys and information was collected on basic household demographics, socio economic status, water-handling use, sanitation and hygiene practices and other health-related behaviors. These variables were collected as possible covariates or factors thought to be associated with filter use or disuse. Observational data related to these factors was also collected by the field team.

Study Sites

Hagar and Samaritan's Purse focused BSF program activities in Kompong Thom, Kratie, and Svey Rieng provinces. Although there are filter projects in 11 provinces throughout Cambodia, the majority of filters were installed in communities from these 3 provinces as part of the CIDA Phase I and Phase II funding from 2001-2006. CGA has also implemented filters in several provinces however CGA program activities were largest in the provinces of Kandal and Kompong Speu. BSFs included in the cross sectional study was reportedly installed in households in CGA projects since 2002 and in Hagar projects since 1999.

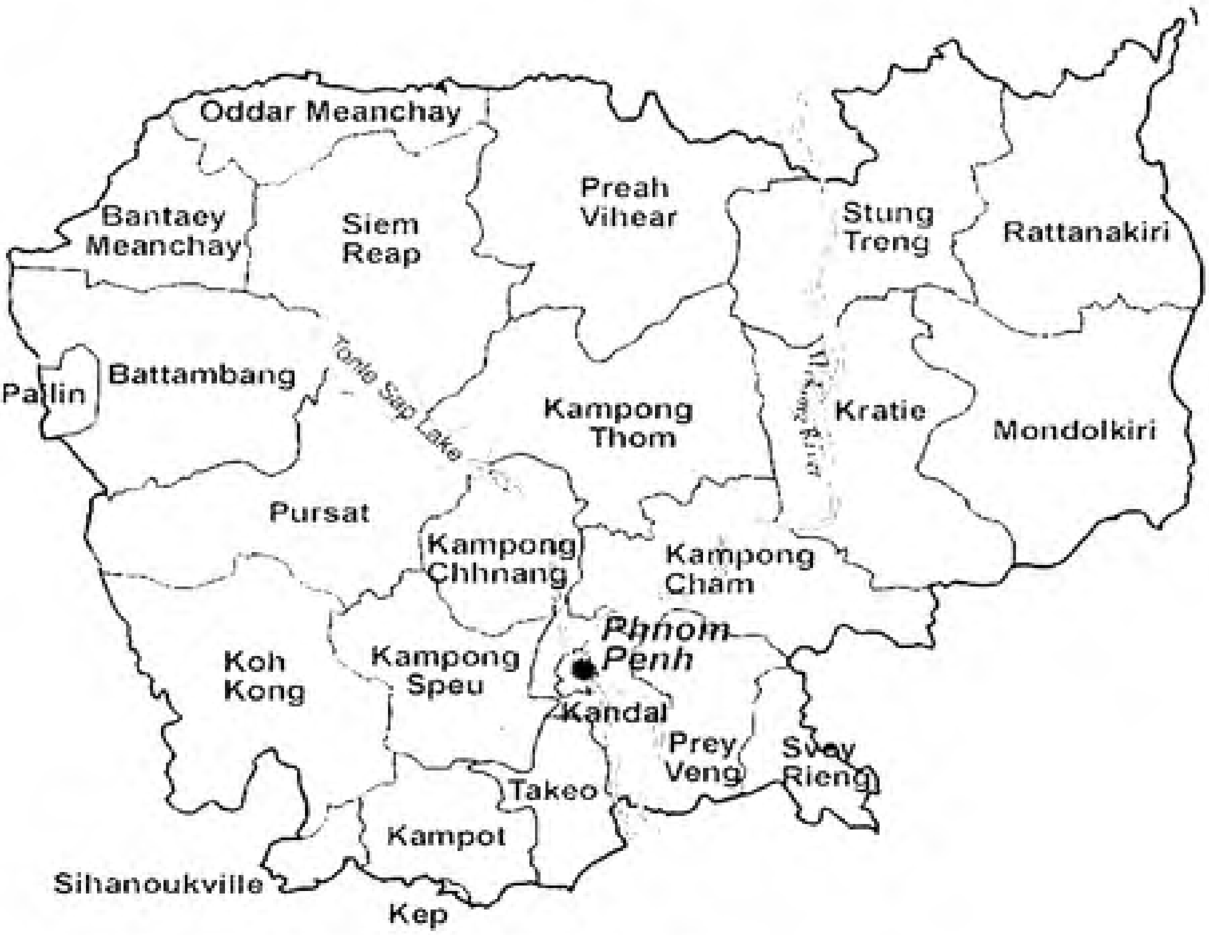


Figure 2 Map of Cambodia (Canby publications co., ltd.)

Definition of Study Population and Random Selection of Households

Both organizations' programs are considered large scale interventions because they are the largest BSF implementation programs to date in Cambodia with over 1000 filters installed across the country (Hagar 22,583, CGA 2668 filters). The study population consisted of households in communities that had twenty or more filters installed throughout the community. Complete lists of households who received filters as part of the BSF programs were compiled from records provided by the NGOs. A master list of all the households from both programs was compiled and households were assigned a number through random number generation by Excel (random number=fractional part of (9821* r + .211327, where r is equal to the previous random number based on the system clock) and randomly selected by Excel Microsoft Office XP Professional version 10.0.2627.01 and STATA version 9. One hundred and seventy-five households from both organization's who had received a filter were randomly selected for the cross sectional study.

Inclusion criteria for participating households in the cross sectional study were: (1) the household had received a filter from the implementing organization, (2) the family or household was living in the original location where they had received the filter, and (3) voluntary willingness to participate in the study. Exclusion criteria for the cross-sectional survey were: (1) the household's or family's unwillingness to participate, and (2) the family or communal unit was no longer living at the location where they had originally received their filter. Each participating household provided a signed informed consent form as demonstration of their willingness to participate in the study. Interviewees unable to provide a written signature provided a fingerprint.

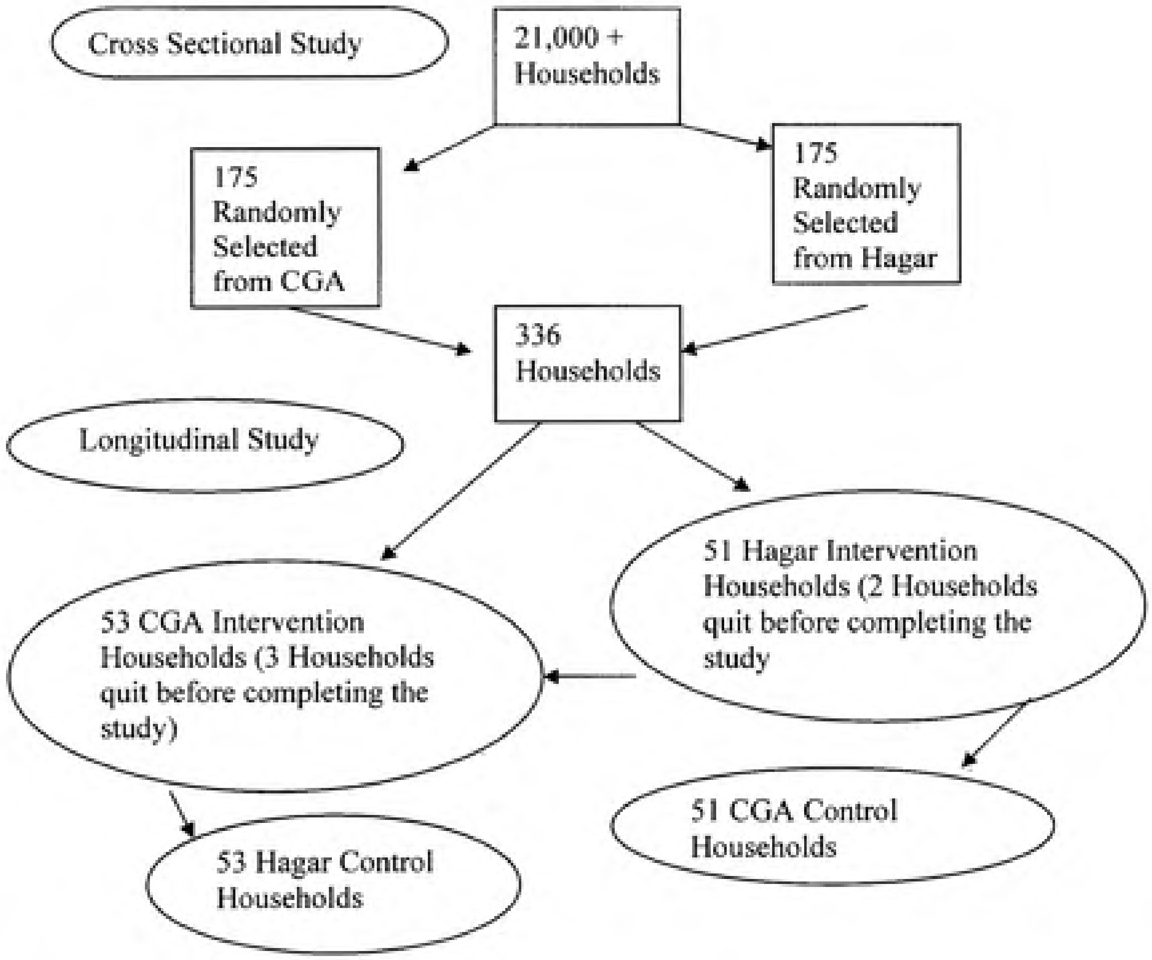


Figure 3 Diagram of household enrollment and participation in the cross-sectional and longitudinal (prospective cohort) study.

Data Collection

The survey instruments were constructed of questions relating to filter use, water handling practices, health, sanitation and hygiene, and socio-economic indicators. Factors that were selected for the evaluation as covariates or potential predictors of filter use such as hand-washing practices, water sources, access to sanitation and socio economic status, are used in similar studies that measured health outcomes related to other water treatment interventions.

The aforementioned factors are considered potential risk factors and indicators for household health, hygiene and sanitation practices. Specifically, these factors are predictors of diarrheal disease rate to environmental factors. These factors were also used in the study on the ceramic water purifiers conducted by Brown and Sobsey in Cambodia in 2006. Similar measurements and methods were used in the BSF study in order to allow for comparisons between factors and technologies.

The survey instruments were prepared in English and then translated into Khmer prior to use in the study. The surveys were back translated from Khmer to English by three separate translators, then translated a second time from English into Khmer and then back translated from Khmer to English a second time to ensure accuracy and appropriateness of each question. The survey used simple and appropriate wording and terminology with predominantly closed (multiple choice) questions. The surveys were then pre-tested in communities that had BSFs but were not included in the study. Revisions were made based on feedback from the interview team of the study and input from the implementing organizations. Some questions were modified from previous survey instruments developed by implementing organizations and some questions were derived from the template provided by the United States Agency for International Development (USAID's) Environmental Health Project.

The project manager and coordinator were responsible for the testing and structuring of the survey instruments and revisions. Survey instruments comprised of over 90 questions and 30 observations and lasted approximately forty-five minutes per household survey. The study team engaged in completing the data collection and analysis involved 1 expatriate and 6 Cambodian national staff. The data collection team, also referred to as the "field team", was managed by the project manager and the project coordinator. Five trained interviewers who were native Khmer speakers and had related prior experience in data collection specifically related to health, collected information from households for the cross sectional survey. Some members of the team were trained by the "Ceramic Water Purifiers" project that had similar field data collection methods (Brown and Sobsey, 2006). The team also had a member designated for GPS data collection and field navigation.

Data for the cross sectional study was collected from the months of November 2006 to January 2007. Survey information was gathered through interviews at participating households and signed informed consent forms were obtained by the data collection team upon initial contact with recruits from candidate study households and prior to any survey questions being asked of participants. Households were given a copy of the informed consent form before the interviewers proceeded with the survey.

Data Entry and Management

The questionnaires/surveys were administered verbally by interviewers to participants at households and the responses were recorded onto survey questionnaire sheets. Completed questionnaires were reviewed by the project manager after each household visit. Data was then transferred from hard copy into Excel spreadsheets by the data collection staff. Households were assigned a unique identifier code and each individual members of the household were also coded based on household. Original hard copy surveys and data sheets were stored at the laboratory office in bound notebooks and files that were locked and accessible by authorized project staff. Electronic files containing household data were also protected by passwords. All data was entered into Microsoft XP Excel files and imported into Stata (initial data in version 6 and final data in version 9), excluding personal identifiers and names of study participants. All data was entered twice and reviewed by the project manager for accuracy of data entry and to control for transcription errors.

Analytic Approach

Data from the cross sectional and longitudinal studies were analyzed to determine factors associated with long term filter use and to measure effectiveness of the BioSand filter and other water treatment methods based on improving water quality and a comparison of diarrhea rates in filter and non-filter (control) households. The main outcome variable in the cross sectional survey was filter use at the time of the survey. A logistic regression model was employed using filter use at time of follow up as a binary outcome variable. Measured covariates were tested for independent associations with the filter use at the time of follow up. To determine factors associated with filter use, odds ratios, 95% confidence intervals and frequencies were determined using Stata version 9. An unadjusted odds ratio was first generated and then stratified by various covariates prior to building a logistic regression model in order to analyze the data. Factors such as date of installation, time in use, breakage rate, reasons for disuse, and other covariates were examined for potential association with filter use or disuse and possible indicators of uptake rate and sustainability.

Materials

The interview team collected survey data on hard copy data sheets and entered the data into Excel spreadsheets. The team also used tape measures and flashlights to assist with various measurements, such as observation of the presence and depth of the biofilm in the filter. In addition to the questionnaires used at each household, pictures of filters were taken for project records. GPS equipment (ETrexx) and software from the RDI (Research

Development International) lab was also used to locate households and their way points for future visits.

Longitudinal Prospective Cohort Study Design and Methods

Study Design

Households that met eligibility criteria for the longitudinal (prospective cohort) study were recruited from the cross sectional survey, for the prospective cohort follow up study. The purpose of the longitudinal study was to determine the health effects, specifically the reduction of diarrhea, and microbial effectiveness (*E. coli.* reduction) of the BSFs in user households compared to non BSF households (controls).

Sample Size Calculations

Using several analytic approaches (see Appendix A), a minimum of 417 individuals were calculated to be included in each study arm of the longitudinal prospective cohort study in order to yield a statistically significant detectable risk ratio of 0.75 between the study groups at 75% power and $\alpha=0.05$. In the Fewtrell et al analysis, the random effects estimate was approximately 30% for water quality interventions and health effects. Based on the risk ratio from the meta analysis conducted by Fewtrell et. al, 2005, an average risk of 25% was estimated for this study in order to accommodate the length of the study and a more conservative estimate of reduction for diarrheal disease. An average of 5 people per household (a conservative estimate), requires a minimum of 72 households per group (intervention and controls). Over 100 households were recruited from each arm, over 50 from each organization for both groups (intervention and controls) in order to compensate for possible attrition. This is a conservative sample size based on previous work and literature. The sample size calculation followed this equation:

STATISTICAL POWER ANALYSES

The statistical power analysis algorithm of Diggle, Heagerty, Liang, and Zeger (2002) for estimating sample-size requirements in studies with a binary outcome measure is adapted here for a two-tailed test:

$$m = \frac{[z_{\alpha/2}\sqrt{2\bar{p}\bar{q}} + z_{\beta}\sqrt{p_A q_A + p_B q_B}\,]^2 (1 + (n-1)\rho)}{nd^2} \qquad (1)$$

Random Selection

Households were initially randomly selected by clustered random sampling methods and random number generation from the original list of household recipients provided by the implementing NGO's. Over fifty households were randomly selected from Hagar project sites in Kompong Thom, Kratie, and Svey Rieng. More than fifty households were also enrolled in the study from AOG/CGA project sites in Kandal and Kompong Speu. In order to gather apportioned representation of intervention households, communities were included from all villages that had more than twenty filters in the town, village, or commune from each province, from each year since the introduction of the filters in the community. Each household was identified as a communal unit or family and data was collected on each subject that was part of the household.

Study Population & Household Enrollment

Each household recruited for the prospective cohort study from the cross sectional study was matched with a non-intervention (control) household located within 1km from the intervention house. The first fifty households that agreed to participate from each organization were enlisted in the study and a control household was identified and recruited by the field team. All participating families were also required to have a child under the age of five living in the house since diarrheal disease reduction in children was a main outcome of interest to the study.

Households recruited as a control non BSF household shared a similar water source as the corresponding intervention household and were in a similar socioeconomic stratum as determined by the questionnaire data (based on monthly electricity payment, household inventory of possessions and observational data). Control households were intended to be as similar as possible to the intervention BSF households. Respondents were also asked to provide information on water handling practices, use, filter use, user satisfaction, sanitation and, health and hygiene.

The inclusion criteria for the longitudinal study were: (1) voluntary willingness to participate in the study, (2) store water in the home, (3) currently using a BSF in the household that originally received the filter (intervention households), (4) a household in the same community but without a BSF, and use the same water source or similar water sources for household water as BSF households (reference or control households), (5) a child under 5 years of age as a household member at the time of the first household visit, and (6) do not use commercial bottled water as their primary source of household drinking water.

The exclusion criteria for the study were: (1) unwillingness to participate, (2) no child under the age of 5 in the household at the time of the first visit, (3) primary or exclusive use of commercial water (sold to consumer, bottled) as drinking water in the home and, (4) unavailability of a consenting matched household in the other study group.

The preparation of survey questionnaires and instruments followed the procedures and steps described for the cross-sectional survey. The questions were pre-dominantly closed questions (multiple choice). Survey instruments included modified questions from previous surveys conducted by implementing organizations and the Ceramic Water Filtration Project in Cambodia to provide consistent and comparable data. As required by the Biomedical Institutional Review Board (IRB) on Research Involving Human Subjects, the Office of Human Research Ethics, the University of North Carolina at Chapel Hill, USA, and the Ministry of Rural Development, Kingdom of Cambodia, informed consent was obtained from each participating household prior to their involvement or collection of any data was gathered. All survey instruments and methods were also reviewed and approved by the Biomedical IRB and the Ministry of Rural Development including project activities and methods.

Data Collection

The field team responsible for the collection of household and village data was composed of a project manager, and four interviewers as well as a GPS and logistics manager. The field team members were trained and experienced community health data collectors, some of whom were recruited from the earlier Ceramic Water Filter Project. The field staff visited each household five times (approximately once a month) from January 2007 to May 2007. Households were located with the assistance of the implementing organizations (CGA and Hagar). GPS data for some households, maps and other locational information and assistance from their project staff was also provided during the data collection period. The field team gathered GPS coordinates and other locating information for each household and recorded the data for future visits.

The primary respondent or head of household acted as the main correspondent for the house during the initial visit and subsequent visits by the data collection team to the household. This individual was queried to determine if the household met inclusion criteria. The consent form was translated from English into Khmer and back translated, and it was also piloted in the field to ensure accuracy and appropriateness. Subjects read or were read the entire contents of the form in Khmer by trained project staff. Households were then presented with a narrative description of the project (both written and oral) and requested to provide information for three to five subsequent visits. Participating households were also requested to provide water samples at each visit. If households agreed to the requests, the individual identified as the primary respondent or head of household signed the informed consent form representing consent for all the individuals in the house. A signed copy was obtained from each primary respondent from each household. In the case that an individual was unable to provide a signature, a fingerprint was taken. A copy of the form was left with the household and another copy was taken for project records and filed in a secure location.

Diarrheal disease point prevalence and incidence for each family member was also collected at each visit. At each home, the household primary caregiver was interviewed to determine diarrheal disease episodes for each family member. Cases of diarrhea were measured by person time based on a 7 day recall period and compared between the household groups. Diarrhea was defined as three or more loose, watery stools in a 24-hour period within the past 7 days, or any stool with the presence of blood, as defined by the World Health Organization (WHO). Three types of water samples were obtained at each visit from each intervention household: the water source, the effluent or filtered water and stored water. The control households provided a sample from their drinking water source and stored water in the household.

The field team collected water samples for analysis at the field laboratory in Kien Svay. The samples were analyzed to determine the effectiveness of the BSF filters in reducing concentrations of fecal indicator microbes present in drinking water sources. *E. coli* was the key bacterial indicator used in this study, measured by membrane filtration techniques according to Standard Methods (Clesceri et al., 1998). Intervention households were sampled for untreated source water, effluent treated water, and stored water. Samples were drawn from control households for analysis including raw source water and water from stored water containers, each sample was 250ml. For samples that were obtained the physical parameters of pH and turbidity was measured and all samples were plated and enumerated in duplicate for total coliforms and *E. coli*. Samples were analyzed within twenty-four hours from the time of collection. Samples collected in Kompong Thom and Kratie province were stored up to 36 hours before analysis.

Data Entry and Management

Household respondents were administered the survey by field staff and recorded onto survey forms and hard copy data sheets. Each household was assigned an identifying code and each individual in the household received a unique code corresponding to the household code. All surveys, visits and samples were also assigned a code representing the household from which the samples were taken and the date of the visit. The collected survey data were entered into Excel spreadsheets. Electronic data were protected by passwords and hard copies of information were stored in locked laboratory cabinets, accessible only by authorized project managers. Water quality data were entered onto hard copy forms and daily entered into Excel spreadsheets also protected by passwords, accessible only to authorized project staff. Data was copied from Excel into Stata (intercooled version 6, version 9) excluding personal identifiers of study participants. All data were entered twice and reviewed by the project manager to ensure accuracy and to prevent transcription errors. Data were entered monthly after all visits for that particular survey cycle of all households had been completed.

Water Quality Analysis and Laboratory Facilities

The purpose of water quality sampling in filter households was to determine the effectiveness of the BSFs at reducing microbes in drinking water. Samples of 250 ml were put into sealable plastic bags and placed in coolers for transport back to the laboratory in Kien Svay. Samples were kept cool until analysis was conducted by trained laboratory personnel, usually within a 24-hour period. The samples were measured for indicator organisms: total coliforms and *E. coli*, by a standard membrane filtration (MF) technique described below and concentrations were reported as colony forming units (CFU) per 100mL. The water samples were also measured for the physical parameters of pH and turbidity using a pH meter and a turbidimeter, respectively. All of the samples were analyzed in duplicate for bacteria, using a minimum of 2 10-fold dilutions as well as positive and negative controls.

Laboratory analyses were conducted in the UNC-funded environmental microbiology laboratory at Research Development International – Cambodia (RDIC) in Kien Svay, Kandal province, Cambodia. The laboratory was a climate controlled, access controlled, secure facility that was adjacent to an RDI-C environmental chemistry laboratory also used by guest researchers from Stanford University and other collaborating universities.

Water quality analysis using membrane filtration for enumeration of total coliforms and *E. coli*, and instrumental measurement of turbidity and pH were done following procedures in Standard Methods for the Examination of Water and Wastewater (APHA, 1998). For MF analysis Petri dishes (55 mm diameter, glass; purchased locally from Kvang Hseieng Medical Instruments) were labeled according to date and household code as well as sample bottle number. Sterile 45mm diameter absorbent pads (Fisher Scientific) were placed into glass Petri dishes and 1.5 mL of Rapid HiColiform broth (HiMedia Laboratories Pvt. Ltd.) were applied by pipette to the pad. Water samples were filtered through membrane filters secured in sterile, 300mL Millipore magnetic filter funnels placed onto a vacuum manifold fabricated by RDI. Membranes were then placed onto the absorbent pads in Petri dishes and duplicates were completed for each water sample dilution. Negative and positive control samples were also analyzed. Samples were placed in the incubator for 16 - 20 hours at 37.5 degrees celcius. Samples were then scored for total coliform and *E. coli* colonies on each duplicate sample plate and recorded on data sheets. Turbidity was measured by a Hach turbidimeter and pH was measured by a Hach pH meter. All reusable lab ware was washed with soap and water, rinsed in tap and reagent water, autoclaving for 35 minutes at 121°C at 1.2 kg/cm2 temperature and pressure, and placed back in designated storage areas. Disposable lab materials were taken to the laboratory ovens and destroyed by fire. All surfaces were cleaned by alcohol regularly and laboratory staff wore gloves and medical masks during the handling and processing of all samples.

Analytic Approach

Data from survey instruments and water quality testing was analyzed by using stratified or tabular analyses and log-regression to identify trends in microbial concentrations in water, physical-chemical water quality (turbidity and pH) as well as diarrheal disease prevalence. This analysis was used in order to identify differences between the two household groups, those using a BSF and those without a BSF. Similar to the ceramic water purifier study, in order to control for clustering of diarrheal disease within households and within individuals over time, a Poisson extension of generalized estimating equations (GEE) was employed in log-risk regression analysis (Zeger and Liang 1986; Liang and Zeger 1986), a standard tool used in the analysis of longitudinal health data (Brown et.al, 2006). Descriptive analyses of the filter's impacts on water quality based on levels of E. coli bacteria and turbidity were also performed. The effect of the BSF on diarrheal disease rates of BSF users (intervention households) compared to non BSF (control households) was determined by comparing incident cases of diarrhea for each group. The odds ratios were calculated and then stratified by age, sex and province.

Variable	Description	Coding
Diarrheal disease	Whether or not participant was experiencing case of diarrheal disease during visit	0 = no diarrhea 1 = case diarrhea
Intervention group	Main exposure variable. It is generated at the household level and describes whether or not the household was selected into the filter group or control group.	0=control group 1=intervention group
Gender	Participant's gender	0=male 1=female
Age	Participant's age	0= if <2 years of age 1= 2-4 years of age 2= 5 years of age and older
Province	The location where household is from	1 = Kandal 2= Kompong Speu 3= Svay Rieng 4= Kompong Thom 5= Kratie

Table 1 Variables and coding used in logistic regression stepwise elimination procedure

Inducements to Participate

All participating households in the study were provided with a household water and hygiene kit that included a 20L water storage container with a sealable lid, multi-purpose soap, cleaning brush, and oral rehydration sachets at the completion of the study (after final surveys and water samples collected) as material compensation for their willingness to participate in the study. The water kits were provided at no cost to the household and distributed by the field team in July 2007, after the fifth visit.

Chapter III

Results: Cross Sectional Study

Study Participants and Households

A total of 336 households from 5 provinces (Kandal, Kompong Speu, Svay Rieng, Kompong Thom, and Kratie) participated in this phase of the study, which was conducted from the end of November 2006 to the beginning of January 2007. The 336 households had a total of 1964 individuals, with an average of 5.86 people per household. Of the total number of individuals, 50.7% were females.

There were 136 households from Kandal province, 30 from Kompong Speu, 53 from Svay Rieng, 59 from Kompong Thom and 58 from Kratie enrolled in the study. More households were selected from Kandal province because most of CGA filters had been installed in that province. Table 2 presents a summary of the number of households selected for the cross-sectional survey, based on information from each organization and grouped by village, commune, district and province.

Organization	Villages	Commune	District	Province	Households
CGA	19	7	4	1,2	166
HAGAR	107	46	12	3,4,5	170
TOTAL	126	53	16	5	336

Table 2 Summary of households and locations in cross sectional survey

The following table is a summary of numbers and percentages of households that reported using the filter or were not using the filter at the time of the survey. The table combines the results from all provinces measured for key water, sanitation and hygiene variables such as filter training, water sources, handling practices, sanitation access and hygiene that were further analyzed for association with filter use or non filter use in subsequent tables.

	Using the BSF	Non Users of BSF
Reported Filter Use	294 (87.5%)	42(12.5%)
Received BSF Training on Operation and Maintenance		
Yes	184 (63%)	19 (45%)
No	109 (37%)	23 (55%)
Storage Container Covered		
Yes	225 (77%)	37 (88%)
No	66 (22%)	5 (12%)
Observed Method of Drawing Water from Stored Container		
Tap	53 (18%)	17 (40%)
Dipper	241 (82%)	25 (60%)
Reported Water Source During Rainy Season		
Surface Water		
Deep Well	103 (35%)	19 (45%)
Rainwater	141 (48%)	11 (26%)
Other (includes taps in	11 (14%)	7 (17%)
and outside of house,	8 (3%)	5 (12%)
purchased water)		
	174	24
Secondary Source Used During Rainy Season Households)		
Surface Water	9 (5%)	3 (13%)
Deep Well	1 (0.6%)	0 (0%)
Rainwater	154 (88.5%)	20 (83%)
Other	10 (6%)	1 (4%)
Access to Sanitation		
Yes	173 (59%)	28 (67%)
No	121 (41%)	14 (33%)
Soap In House At Visit		
Yes	285 (97%)	39 (81%)
No	7 (2.4%)	3 (7%)
Missing	2 (0.7%)	
Wash Hands With Soap		
Yes	238 (81%)	34 (81%)
No	28 (9.5%)	6 (14%)
Other	28 (9.5%)	2 (5%)

Table 3 Summary of key variables separated by filter use and non-use

Data on water use and handling practices, sanitation and hygiene, and wealth was collected across the five provinces and several villages during the cross-sectional study and are summarized in Table 3 above. The key variables related to water sources, water use and handling practices and are outlined in greater detail according to province in tables below and separated based on filter use or non use.

Filter Use

Of the households surveyed, 87.5% (294 households) reported they were currently using the BSF filter at the time of the visit. To determine if the filter was in use the field team also checked by visual inspection and observations to determine if it was functioning. This was also confirmed by checking flow rates and asking the last time the household had used the filter. Filters were considered to be in use if the household had reported using the filter atleast once within the past week or were using the filter daily. There were 42 households (12.5%) that reported not using the filter, but all respondents had reported having used the filter at some point. Of the households that reported use of the filter, 9 respondents (3%) reported pouring less than a full container of untreated water into the filter a day. Eighty five households (29%) reported filtering a full container atleast once a day, 102 households (35%) used the filter for filtering two containers of untreated water, 59 (20%) reported 3 uses and 13 (4%) reported using the filter more than 4 times a day. Households reported using an average of forty six liters of water from the filter of which an average of 13.6 liters per day was used by the family specifically for drinking.

Among households that reported using the filter, 184 (63%) reported receiving training on the BSF operation and maintenance, 109 (37%) reported they did not. Two hundred and twenty-five households (77%) who reported using the filter also covered their water storage container. There were 66 households among those who reported using the filter who also reported they did not cover their storage container (22%). Among non filter users, 19 (45%) reported receiving BSF training, and 23 (55%) reported they did not.

Using filter at time of follow up *(294 Households)						
Province	Kandal 118 (40%)	Kompong Speu 27 (9%)	Svay Rieng 53 (18%)	Kompong Thom 53 (18%)	Kratie 43 (15%)	Total 294 (100%)
Received Training on BSF Maintenance and Operation						
Yes	64 (54.2%)	16 (59.2%)	34 (64.2%)	34 (64.2%)	36 (83.7%)	184 (63%)
No	54 (45.8%)	11 (40.7%)	18 (34%)	19 (36%)	7 (16%)	109 (37%)
Missing	0%	0%	1 (1.9%)	0%	0%	1 (0.3%)
Observed Method of Drawing Water						
By pouring/Tap	25 (21.2)	3 (11.1%)	7 (13.2%)	10 (18.9%)	8 (18.6%)	53 (18%)
Dipper or other container	93 (79%)	24 (89%)	46 (86.8%)	43 (81.1%)	35 (81.4%)	241 (82%)
Container for Treated						
Traditional Jar or Ceramic Pot	3 (2.5%)	3 (11.1%)	19 (35.9%)	9 (17%)	2 (4.7%)	36 (12%)
Plastic Bucket or Container	89 (75.4%)	19 (70.4%)	28 (52.8%)	38 (71.7%)	31 (72%)	205 (70%)
Metal Bucket or Container	1 (0.9%)	2 (7.4%)	0 (0%)	0 (0%)	1 (2.3%)	4 (14%)
Other	17 (14.4%)	3 (11.1%)	0 (0%)	2 (3.8%)	4 (9.3%)	26 (9%)
Missing	8 (6.8%)	0 (0%)	6 (11.3%)	4 (7.6%)	5 (11.6%)	23 (8%)
Covered Water Storage Container						
Yes	91 (77.1%)	19 (70.4%)	43 (81.1%)	39 (73.6%)	33 (76.7%)	225 (77%)
No	24 (20.3%)	8 (29.6%)	10 (18.9%)	14 (26.4%)	10 (23.3%)	66 (22%)
Missing	3 (2.5%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (1%)

Table 4 Variables and filter use by province

Filter Management and Use

Of the households using their filter, 242 (82%) reported knowing the proper method for cleaning the top layer of sand, and 40 household (14%) did not know. When asked whether the household knew the steps for restoring the flow rate, 97 households (33%) described all the steps, 142 households (48%) could describe some of the steps, and 55 (19%) did not know the steps for restoring the flow rate. Most households (76%, 223 households) using the filter reported cleaning the filter spout within a month from the visit; the other respondents could not remember or reported never cleaning the spout (71 households, 24%).

Main Drinking Water Source Rainy Season Water Source (294 Households)	Kandal	Kompong Speu	Svay Rieng	Kompong Thom	Kratie	Total
1. Tap in House	0 (0%)	0 (0%)	0 (0%)	1 (1.9%)	2 (4.7%)	3 (1%)
2. Tap outside of House	0 (0%)	0 (0%)	0 (0%)	1 (1.9%)	1 (2.3%)	2 (0.7%)
3. Shallow well	4 (3.4%)	5 (18.5%)	2 (3.8%)	26 (49.1%)	3 (6.9%)	40 (14%)
4. Deep Well >10m	51 (43.2%)	13 (48.2%)	51 (96.2%)	9 (17%)	17 (39.5%)	141 (48%)
5. River, Stream, Channel	31 (26.3%)	2 (7.4%)	0 (0%)	4 (7.6%)	11 (25.6%)	48 (16%)
6. Lake, Pond	7 (6%)	4 (14.8%)	0 (0%)	4 (7.6%)	0 (0%)	15 (5%)
7. Rainwater	24 (20.4%)	3 (11.11%)	0 (0%)	6 (11.32%)	9 (21%)	42 (14%)
8. Purchase water	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
9. Other	0 (0%)	0 (0%)	0 (0%)	2 (3.8%)	0 (0%)	2 (0.7%)
Missing	1 (0.8%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (0.3%)
Using a Second Source						
2. Tap outside of House	0 (0%)	0 (0%)	0 (0%)	1 (2%)	0 (0%)	0 (0%)
4. Deep Well >10m	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (2.3%)	1 (0.3%)
5. River, Stream, Channel	1 (0.9%)	1 (3.7%)	0 (0%)	0 (0%)	1 (2.3%)	1 (0.3%)
6. Lake, Pond	3 (2.5%)	3 (11.1%)	0 (0%)	0 (0%)	0 (0%)	3 (1%)
7. Rainwater	82 (69.5%)	16 (59.3%)	16 (30.2%)	18 (34%)	22 (51.2%)	6 (2%)
8. Purchase Water	1 (.85%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	154 (52%)
9. Other	3 (2.5%)	1 (3.7%)	0 (0%)	3 (5.7%)	1 (2.33%)	1 (0.3%)
Missing	28 (23.7%)	6 (22.2%)	37 (69.8%)	31 (58.5%)	18 (42%)	8 (3%)

Table 5 Water sources and filter use

Water Sources and Filter Use

When examining the water sources that households used in the rainy season, households were grouped if they reported using any of the three main sources: surface water (lakes, ponds, river, streams, canals, channels and shallow wells), deep wells (>10m) and rainwater. Each group was collapsed into dichotomous variables and divided based on use of the filter at the time of follow up or not using the filter at the time of follow up. Using a deep well as one of the household's source was reported for 43% (51 households) in Kandal, 48.15% (13 households) in Kompong Speu, 96.23% (51 households) in Svay Rieng, 16.98% (9 households) in Kompong Thom, and 40% (17 households) in Kratie.

For households that reported using the filter, the following water sources were reported with the highest use: surface water (112 households, 38%), deep wells (142 households, 48%) and rainwater (165 households, 56%). The source reported least used was taps outside the house and no households reported using purchased bottled water which was considered "other" in the table above and amounted to 24 households in total (7%).

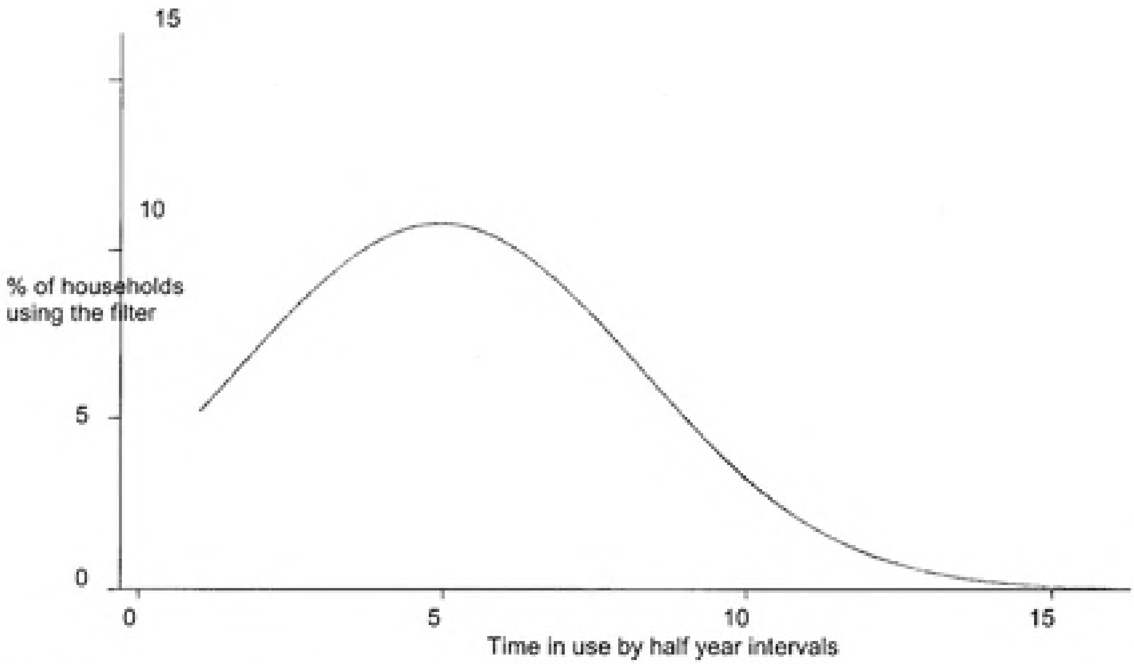
For the variable of distance from the home to the water source, 159 of the 336 households (47%) households reported traveling less than 10m to get their water, 151 households (45%) traveled less than 100m, 25 households (7%) reported a distance between 100-500m to the water source and one house reported traveling between 0.5km - 1km. Of 336 total households, nearly all (333 or 99%) reported using a container to store water.

Time in Use

Graph 1 below shows a summary of the length of time the filters have been in use of those that were included in the cross-sectional survey. The tables below are showing the number of households that reported using the filters and the non users separated by province, and the length of time in use. There were filters that had been installed as part of the first phase of the CIDA funding by Hagar and Samaritan's Purse (8 years from the date of visit). In this study, a small fraction of filters that had been in use for over 5 years were selected for the study. The bars represent the period of time the filters were in use and the percent that were installed during each time period. The time in use is an indication of filter uptake and sustainability of the BSF in households. The ceramic water purifier study conducted in Cambodia prior to the BSF study found that there was a strong association with the length of time elapsed between filter installation in the household and follow up mostly due to breakage rates. Many households who had a ceramic water purifier were not in use after two years since installation. However, there were forty-one BSF households that provided a date of installation and reported using the BSF for greater than 4 years (41/280, 15%). Of all filters that had been in use for more than 4 years, 90% were reportedly in use.

Years since implementation for BSF users	Kandal	Kompong Speu	Svay Rieng	Kompong Thom	Kratie	Total
0-.5	26 (22%)	10 (37%)	10 (18.9%)	1 (2%)	1(2.3%)	48 (16%)
.5-1	17 (14.4%)	1 (3.7%)	5 (9.4%)	6 (11.3%)	7 (16.3%)	36 (12%)
1-1.5	17 (14.4%)	1 (3.7%)	6 (11.3%)	0%	1(2.3%)	25 (8.5%)
1.5-2.0	13 (11%)	3 (11.1%)	16 (30.19%)	3 (5.7%)	7 (16.3%)	42 (14%)
2.0-2.5	11 (9.3%)	3 (11.1%)	3 (5.7%)	0%	0%	17 (6%)
2.5-3.0	6 (5.1%)	5 (18.5%)	7 (13.2%)	8 (15.1%)	6 (14%)	32 (11%)
3.0-3.5	7 (5.9%)	3 (11.11%)	3 (5.7%)	3 (5.7%)	3 (7%)	19 (6.5%)
3.5-4.0	4 (3.4%)	1 (3.7%)	0%	10 (18.9%)	5 (11.6%)	20 (7%)
4.0-4.5	5 (4.2%)	0%	1 (2%)	2 (3.8%)	2 (4.7%)	10 (3%)
4.5-5.0	5 (4.2%)	0%	1 (1.9%)	6 (11.3%)	5 (11.6%)	17 (6%)
5.0-5.5	0%	0%	0%	0%	0%	0 (0%)
5.5-6.0	0%	0%	0%	4 (7.6%)	1(2.3%)	5 (2%)
6.0-6.5	1 (0.985%)	0%	0%	0%	0%	1 (0.3%)
6.5-7.0	0%	0%	0%	5 (9.3%)	2 (4.7%)	7 (2%)
7.0-7.5	0%	0%	0%	0%	0%	0 (0%)
7.5-8.0	0%	0%	0%	1 (1.9%)	0%	1 (0.3%)
Total installed per province	112 (94.9%)	27 (100%)	52 (98%)	49 (92.5%)	40 (93%)	280 (95%)
Missing Dates	6 (5.1%)	0%	1 (2%)	4 (7.6%)	3 (7%)	14 (5%)

Table 6 Filters time elapsed since installation for filter users



Graph 1 Filters elapsed time since installation, percentages of filters installed during half year periods

Filter Disuse

Of the 336 filter households that were included in the study, 42 (12.5%) households reported that they no longer used the filter. Of the houses that no longer use the filter, half provided a response/reason for their disuse. Thirteen respondents said the reason for disuse was related to dissatisfaction with color, taste or smell of the water from the BSF. Six households reported that they discontinued use because they were unable to fix a problem they encountered or felt that the BSF did not work how they expected. Two households said they gave the filter away (5%). For non filter users, 37 households (88%) covered their storage containers and 5 (12%) did not.

Not Using filter at time of follow up *(42 Households) Province	Kandal 18	Kompong Speu 3	Svay Rieng 0	Kompong Thom 6	Kratie 15	TOTAL 42
Years since implementation						
0-1	2(11.1%)	0 (0%)	0 (0%)	0(0%)	4(26.7%)	6 (15%)
1-2	4 (22.2%)	0 (0%)	0 (0%)	2 (33.3%)	4(26.7%)	10(24%)
2-3	5 (27.8%)	1 (33.3%)	0(0%)	1(16.7%)	3(20%)	10(24%)
3-4	1(5.6%)	1(33.3%)	0(0%)	0(0%)	2(13.3%)	4(10%)
4-5	3(16.7%)	0 (0%)	0 (0%)	0(0%)	0(0%)	3(7%)
5-6	0(0%)	0 (0%)	0 (0%)	0 (0%)	1(6.7%)	1(2%)
6-7	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0(0%)	0(0%)
Total installed per province	15 (83.3%)	2 (66.7%)	0 (0%)	3 (50%)	11(73.3%)	34(81%)
Missing Dates	3 (16.7%)	1 (33.3%)	0 (0%)	3 (50%)	1 (6.7%)	8(19%)
Container for Treated						
Traditional Jar or Ceramic Pot	1 (5.6%)	0 (0%)	0 (0%)	0 (0%)	1 (6.7%)	2(5%)
Plastic Bucket or Container	4 (22.22%)	1 (33.3%)	0 (0%)	2 (33.3%)	11 (73.3%)	18(43%)
Metal Bucket or Container	0 (0%)	0 (0%)	0 (0%)	1 (16.67%)	1 (6.7%)	2(5%)
Other	13 (72.2%)	2 (66.7%)	0 (0%)	2 (33.3%)	0 (0%)	17(41%)
Missing	0 (0%)	0 (0%)	0 (0%)	1 (16.7%)	2 (13.3%)	3(7%)
Covered Water Storage Container						
Yes	15 (83.3%)	3 (100%)	0 (0%)	5 (83.3%)	14 (93.3%)	37(88%)
No	3 (16.7%)	0 (0%)	0 (0%)	1 (16.7%)	1 (6.7%)	5(12%)
Missing	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0(0%)

Table 7 Non filter users and water use and handling variables by province

Water Sources and Filter Disuse

The 12.5% of households that no longer used the filter were mostly using rainwater (28 households, 67%) as one of their sources followed by deep well (11 households, 26%) and surface water (shallow well, rivers, lake, pond, etc.) (27 households, 64%) shown in the table below that includes all sources reportedly used by households not using the filter.

Source	Not Using Filter	Using Filter
1. Tap Inside	6	3
2. Tap Outside	0	3
3. Shallow Well	8	40
4. Deep Well	11	142
5. Surface Water	11	51
6. Lake or Pond	8	21
7. Rainwater	28	207
8. Purchased	0	3
9. Other	0	11
Total	42	294

Table 8 Summary of water sources used during the rainy season

The following table shows the households not using the water filters and their drinking water sources in the rainy season, separated by province. Households may change water sources depending on the season and availability and access to water. In the rainy season, families have increased access to rainwater and surface water. The microbiological water quality and diarrheal disease rates differ by water source and by season. For non filter users, according to the data presented in Table 9, most households used a deep well followed by rainwater, surface water sources and shallow wells. Totals for households using the source, summarized in the table above was calculated based on whether the household had ever reported using the source at any time during the rainy season.

Main Drinking Water Source Rainy Non filter users	Kandal (18)	Kompong Speu (3)	Svay Rieng (0)	Kompong Thom (6)	Kratie (15)	Total (42)
Water Source						
1. Tap in House	1 (5.6%)	0 (0%)	0 (0%)	1 (16.7%)	3 (20%)	5 (12%)
2. Tap outside of House	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
3. Shallow well	1 (5.6%)	0 (0%)	0 (0%)	3 (50%)	4 (26.7%)	8 (19%)
4. Deep Well >10m	7 (38.9%)	2 (66.7%)	0 (0%)	1 (16.67%)	1 (6.7%)	11 (26%)
5. River, Stream, Channel	4 (22.2%)	0 (0%)	0 (0%)	1 (16.7%)	4 (26.7%)	9 (21%)
6. Lake, Pond	2 (11.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (5%)
7. Rainwater	3 (16.7%)	1 (33.3%)	0 (0%)	0 (0%)	3 (20%)	7 (17%)
8. Purchase water	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
9. Other	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Missing	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Using a second source						
1. Tap in House	1 (5.6%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (2%)
2. Tap outside of House	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
4. Deep Well >10m	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
5. River, Stream, Channel	1 (5.6%)	0 (0%)	0 (0%)	0 (0%)	1 (6.7%)	2 (5%)
6. Lake, Pond	1 (5.6%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (2%)
7. Rainwater	9 (50%)	1 (33.3%)	0 (0%)	2 (33.3%)	8 (53.33%)	20 (48%)
8. Purchase water	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
9. Other	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Missing	6 (33.3%)	2 (66.7%)	0 (0%)	4 (66.7%)	6 (40%)	18 (43%)

Table 9 Non filter users and water sources by province

Water Sources

Many households using the filter reported using rainwater as a source as well as a deep well. Households using a deep well may perceive the quality of water from the well to be high but there may also be aversion to using deep wells or groundwater sources in the country because they are also known to contain high levels of naturally occurring arsenic and other chemical contaminates (Feldman et al.2007). Rainwater may be the primary choice followed by deep well water if households are choosing the source based on perceived quality and awareness of arsenic problems in their area. When adjusting for province, rainwater became a significant predictor of whether or not the household was using the filter. This suggests that geographic location influences the source water that is used by households and may have an effect on continued filter use.

For households not using the filter (Table 8) shows households in Kandal province were mostly using deep wells (38.89%) followed by rainwater (12 households, 29%) and surface water (7 households, 17%) . Deep wells were also the largest source for Kompong Speu and rainwater was also reported as a source for non filter users in the province. Kompong Speu showed 10% of the households not using the filter. The largest percentage of households that reported not using the filter, were from Kandal (18 out of 136 households, 13.24%) and Kratie (15 out of 58 households, 26%) province, although 130 households of the 336 households that participated in the study were from Kandal which is the largest BSF project of CGA's water filter program. Kratie respondents reported using mostly shallow wells and rivers equally (both 26.67%) however, when combined as surface water (8 households, 19%). One household reported using a deep well (7% of non filter users use this source).

It is also of interest that of the households not using the filter, the largest number of households that reported boiling the water as a treatment option were from Kandal (18 households, 47%) and Kratie (12 households, 32%) out of 38 households that were no longer using the filter that reported using a treatment method. There were 33 households (78%) that reported that boiling water could prevent diarrhea. Kandal and Kratie also reported the largest numbers of households that believed diarrhea could be prevented by boiling (15 and 6 respectively) out of the households that reported no longer use the filter. Further discussion regarding boiling and association with filter use is discussed in a following paragraph. It is noted here to suggest that Kandal and Kratie have the highest rate of non filter users and also the largest percentage that believe diarrhea can be prevented by boiling water and are the provinces with the highest percentage of households that boil their water.

Water Use and Handling Practices

Respondents used treated water for drinking (331 households or 99%), washing or preparing food (224 households or 67%), washing dishes and kitchen equipment (101 household or 30%), washing hands (32 households or 10%), and for bathing water (24 households or 7%). The study also asked the households if their method of treatment, either the BioSand filter or an alternative method, was sufficient to meet the daily water needs of the family. When asked about BioSand filter accessibility for purchase, 250 households (74%) reported that BSFs could not be purchased in the area, 37 (11%) reported that BSFs could be purchased and 49 (15%) of respondents did not know. If the BSF was broken or has problems, the vast majority of the respondents (219 households or 65%) said they would seek help from the implementing organization (CGA or Hagar), while only 23 (7%) said they would go to a village committee member, 18 (5%) said a local technician should solve the problem, 15 (5%) would try to fix it on their own, and 25 (7%) did not know who to contact if they had a problem with the filter.

Water containers used for storing treated water were typically traditional ceramic or concrete jars or vessels. However, most families had multiple containers and used both traditional and plastic containers. For households storing treated water and using the filter (294 households) the primary storage container was made of plastic (223 households or 76%) followed by other non-ceramic containers (43 households or 1513%) and ceramic pots (38 households or 13%).

Information was also collected on the method for drawing water from the storage container for drinking. Households were separated into two groups based on whether or not they were using a tap or pouring their water, which is considered a safe water dispensing method, or whether they used another instrument such as a cup or a short or long handle container that was dipped into the water container to transfer water for drinking and considered a less safe dispensing method because of the potential for recontamination of the drinking water and containers. A total of 266 (79%) households used some sort of dipper or other instrument to collect water from the treated water storage container, and 70 (21%) households reported having a tap or pouring the water directly into a cup for drinking. No households reported using hands to collect water from the treated water storage for drinking.

When asked about the cause of diarrhea most of the households, (236, 70%) responded that contaminated water was the leading cause followed by food (222, 66%), poor hygiene (222 households, 66%), insects (26 households, 7.7%), children teething (18 households, 5.5%) and other causes (9%), including weather and bad breast milk as the cause for diarrhea in children Ninety-percent of household (301) respondents reported the belief that, diarrhea can be prevented and the remaining 35 (10.4%) households reported that it was not possible to prevent diarrhea.

When households were asked what people should do in order to protect themselves from diarrhea, the reported leading prevention measures were boiling water (262 households, 78%), properly preparing food (252 households, 75%), and cleaning hands (145 households, 43%). Six respondents (2%) reported that they did not know any method for preventing diarrhea. Most households responded with multiple prevention measures.

Sanitation Related to Filter Use and Disuse by Province

Sanitation facilities were defined as using a toilet, latrine or a flush toilet, shared or private. No households were connected to a conventional sewerage system. 201 households (60%) had access to sanitation facilities and 135 (40%) reported using the ground, fields, or plastic bags as places for defecation , which is considered to be no access to sanitation. The province with the least access to sanitation was Kompong Speu (77% no access), followed by Svay Rieng (59%) and Kratie (52%). Access to sanitation was also measured as a possible factor contributing to filter use or disuse. There were 173 households (59%) of filter users that reported having access to sanitation. There were 121 households (41%) that did not have access.

Using filter at time of follow up [a](294 Households)						
Province	Kandal	Kompong Speu	Svay Rieng	Kompong Thom	Kratie	Total
	118 (40%)	27 (9%)	53 (18%)	53 (18%)	43 (15%)	294
Soap observed in the household						
Yes	116 (98.3%)	24 (88.9%)	53 (100%)	51 (96.2%)	41 (95.4%)	285 (97%)
No	1 (0.9%)	3 (11.11%)	0 (0%)	1 (1.8%)	2 (4.65%)	7 (2.4%)
Missing	1 (0.9%)	0 (0%)	0 (0%)	1 (1.8%)		2 (.7%)
Access to Sanitation						
Yes	87 (73.7%)	7 (25.9%)	22 (41.5%)	35 (66%)	22 (52%)	173 (59%)
No	31 (26.3%)	20 (74.1%)	31 (58.5%)	18 (34%)	21 (48.1%)	121 (41%)
Wash hands with soap						
Yes	104 (88.1%)	23 (85.2%)	45 (84.9%)	40 (75.5%)	26 (60.5%)	238 (81%)
No	8 (6.8%)	2 (7.4%)	4 (7.6%)	7 (16.2%)	7 (16.3%)	28 (9.5%)
Other	6 (5.1%)	2 (7.4.%)	4 (7.6%)	6 (11.3%)	10 (23.3%)	28 (9.5%)

Table 10 Filter users and sanitation and hygiene separated by province

For non filter users, 28 households (67%) did have access to sanitation and 14 households (33%) did not. Most households (39 of non filter users, 93%) had soap in the household at the time of visit. The province that reported the least access to sanitation and not using the filter were from Kompong Speu which had no houses with access to sanitation and Kratie (9 households, 60%) of the non filter users in the province. All households in Kandal province who were not using the filter reported they had access to sanitation. Kandal (94% in the province) and Kompong Speu (100%) had the highest rate of households who did not use the filter but reported washing their hands with soap. Kratie reported that for the households not using filter, 73% washed their hands with soap.

Not Using filter at time of follow up *(42 Households)						
Province	Kandal 18	Kompong Speu 3	Svay Rieng 0	Kompong Thom 6	Kratie 15	Total 42
Soap observed in the household						
Yes	17 (94.4%)	3 (100%)	0 (0%)	5 (83.3%)	14 (93.3%)	39 (93%)
No	1 (5.6%)	0 (0%)	0 (0%)	1 (16.7%)	1 (6.7%)	3 (7%)
Missing	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Access to Sanitation						
Yes	18 (100%)	0 (0%)	0 (0%)	4 (66.7%)	6 (40%)	28 (67%)
No	0 (0%)	3 (100%)	0 (0%)	2 (33.3%)	9 (60%)	14 (33%)
Wash hands with soap						
Yes	17 (94.4%)	3 (100%)	0 (0%)	3 (50%)	11 (73.3%)	34 (81%)
No	1 (5.6%)	0 (0%)	0 (0%)	3 (50%)	2 (13.3%)	6 (14%)
Other	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2 (13.3%)	2 (5%)

Table 11 Non filter users and sanitation and hygiene variables separated by province

Household respondents were asked if they and other members of the household washed their hands after defecating or using sanitation facilities. A total of 253 respondents (75%) reported that they always washed hands, 70 (21%) washed their hands sometimes, and 12 (4%) responded that they never washed their hands. Of those households that wash their hands with soap, 274 (82%) households affirmed that the household used soap occasionally or always and 34 (10%) reported that their household never used soap for washing hands but may use just water.

There were 30 households that reported using other materials to clean hands such as sand. Additionally, when asked on what specific occasions members of the household washed their hands, 236 (70%) respondents reported practicing hand-washing after defecation, 189 (56%) households reported washing hands before preparing food, 278 (83%) washed hands after eating, and 76 (23%) reported washing after performing household or caretaking activities.

When asked about the cause of diarrhea most of the households (236 households, 70%) responded that contaminated water was the leading cause followed by food (222, 66%), poor hygiene (222 households, 66%), insects (27 households, 8%), children teething (20 households, 6%) and other causes (30 households, 9%), including weather and bad breast milk as the cause for diarrhea in children According to 301 (90%) household respondents, diarrhea can be prevented and the remaining 35 (10%) households reported that it was not possible to prevent diarrhea. When households were asked what people should do in order to protect themselves from diarrhea, the reported leading prevention measures were boiling water (262 households, 78%), properly preparing food (252 households, 75%), and cleaning hands (145 households, 43%). Six respondents (2%) reported that they did not know any method for preventing diarrhea. Most households responded with multiple prevention measures.

Wealth and Assets Related to Filter Use and Disuse

Most of the filter users were categorized in the middle of the wealth index (202 households, 69%) followed by poor (88 households, 30%) and 4 household were considered wealthy (1%). The province that had the highest number of households categorized as poor was from Kompong Speu and Kratie (52%, 44%) provinces. Kompong Thom had the highest number of wealthy households (2) which is fifty per cent of all the households listed as wealthy, who were using the filter. Households were grouped on the poor to wealthy index based on the number of assets reported by each household. Poor households reported no or one asset, middle was based on two, three or four assets and wealthy reported having five of the assets on the index.

Assets were based on the ownership of the following items: motorcycle or vehicle (car or truck), electricity, housing material, floor material and cows). Most houses that were using the filter reported having 2 assets (107 households, 36%). Kratie showed that there were no households that owned 4 or 5 of the assets listed and also had one of the highest number of households listed as poor (19 households, ten of which had no assets). The province of filter users that had the most assets reported were from Kandal however based on percentage, Kompong Thom households owned more, four or five assets.

Using filter at time of follow up (294 Households)						
Province	Kandal 118	Kompong Speu 27	Svay Rieng 53	Kompong Thom 53	Kratie 43	Total 294
Wealth Index						
Poor	33 (28%)	14 (52%)	10 (19%)	12 (23%)	19 (44%)	88 (30%)
Middle	84 (71%)	13(48%)	41 (77%)	40 (75%)	24 (56%)	202 (69%)
High	1 (1%)	0 (0%)	2 (4%)%	1 (2%)	0 (0%)	4 (1%)
Asset Index						
Households 0 assets	7 (6%)	8 (30%)	6 (11%)	3 (6%)	10 (23%)	34 (12%)
1 asset	26 (22%)	6 (22%)	4 (8%)	9 (17%)	9 (21%)	54 (18%)
2 assets	41 (35%)	7 (26%)	25 (47%)	22 (41.5%)	12 (28%)	107 (36%)
3 assets	35 (30%)	5 (19%)	11 (21%)	14 (26%)	12 (28%)	77 (26%)
4 assets	8 (7%)	1 (3%)	5 (9%)	4 (7.5%)	0 (0%)	0 (0%)
5 assets	1 (1%)	0 (0%)	2 (4%)	1 (2%)	0 (0%)	0 (0%)

Table 12 Filter users and wealth/asset variables separated by province

For households not using the filter, most households were considered as middle in the wealth index (24 households, 57%). Kratie had the largest number of households not using the filter and considered poor (10 households, 67%). Kompong Speu also reported the highest percentage of households considered poor (2 households, 67%). There were no households in the non filter user group that were considered wealthy or reported having 5 assets. Svay Rieng did not have any non filter users therefore are not included in the following table.

Not Using filter at time of follow up *(42 Households)						
Province	Kandal 18	Kompong Speu 3	Svay Rieng 0	Kompong Thom 6	Kratie 15	Total 42
Wealth Index						
Poor	4 (22%)	2 (67%)	0 (0%)	2 (33%)	10 (67%)	18 (43%)
Middle	14 (78%)	1 (33%)	0 (0%)	4 (77%)	5 (33%)	24 (57%)
Wealthy	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Asset Index						
Households with 0 assets	7 (6%)	8 (30%)	6 (11%)	3 (6%)	10 (23%)	34 (12%)
1 asset	26 (22%)	6 (22%)	4 (8%)	9 (17%)	9 (21%)	54 (18%)
2 assets	41 (35%)	7 (26%)	25 (47%)	22 (41.5%)	12 (28%)	107 (36%)
3 assets	35 (30%)	5 (19%)	11 (21%)	14 (26%)	12 (28%)	77 (26%)
4 assets	8 (7%)	1 (3%)	5 (9%)	4 (7.5%)	0 (0%)	18 (6%)
5 assets	1 (1%)	0 (0%)	2 (4%)	1 (2%)	0 (0%)	4 (1%)

Table 13 Non filter users and wealth/asset variables separated by province

Statistical Analysis Comparing Key Variables Related to Filter Use and Disuse

The table below presents combined data for filter and non filter households. The table also presents the estimated odds ratios and 95% confidence intervals for the comparison of these variables between filter use and non-use households by logistic regression, in order to examine if they are associated positively or negatively with filter use. Odds ratio estimates that were greater than one indicate a possible positive association between the variable and filter use and odds ratios less than one indicate a negative association between the variable and filter use. These odds ratios are considered to have a significant association if their 95% confidence intervals do not cross the value of 1.0 (are either below 1.0 or both above 1.0).

	BSF Users 294	Non Users of BSF 42	Unadjusted Odds Ratios OR using logistic regression	Confidence Intervals 95% CI using logistic regression
Reported receiving training on Operation and Maintenance of BSF				
Yes	184	19	2.04	(1.01 - 4.16)
No	109	23		
Missing 1				
Covered water storage Container				
Yes	152	23	0.89	(0.47 - 1.7)
No	141	19		
Missing 1				
Observed method of drawing water for drinking				
Dipper or instrument	241	25	3.09	(1.56 - 6.13)
Pour/Tap	53	17		
Missing 0				
Drinking water sources*				
1. Surface (Yes)	112	21	0.62	(0.32 - 1.8)
All Other Sources	182	21		
2. Deep Well (Yes)	142	11	2.63	(1.27 - 5.4)
All Other Sources	152	31		
3. Rainwater (Yes)	207	28	1.9	(0.59 - 2.37)
All Other Sources	87	14		
Soap Observed in the Household				
Yes	285	7	3.13	(0.78 – 12.6)
No	39	3		
Missing 2				
Wash Hands With Soap				
Yes	238	28	1.5	(0.57 – 3.9)
No	34	6		
Missing 30				
Access to Sanitation				
Yes	173	28	0.72	(0.36 - 1.4)
No	121	14		
Missing 0				

Table 14 Odds ratios and confidence intervals for key variables associated with filter use and disuse

Association of Filter Use and Variables Related to Filter Management and Water Handling Practices

Water Dispensing From Container and Container Cleaning

Method of water dispensing from the household storage container and container cleaning were measured for association with filter use. Of these factors, household use of a dipper 6.13), showed a positive association. Households that cleaned their water storage container had a positive association with filter use (or=14.6, 95% CI 1.29-164.7) but the 95% confidence interval is very wide possibly due to a small control group. A narrow confidence interval shows a strong association and statistical significance because it does not cross the null and is >1. The variable of covering the household water storage container with a cap or a lid was not strongly associated with filter use or disuse (OR=0.89, 95% CI of 0.47 – 1.7).

Sanitation, Hygiene and Diarrhea Beliefs

There was not an association of filter use or disuse with access to sanitation (OR=0.72, 95% CI of 0.36 – 1.4). While the vast majority (324, 96%) of households had soap in the house at the time of visit, it was not specifically associated with filter use (OR= 3.13, 95% CI 0.78 – 12.6). In addition, there was no strong association between washing hands with soap and filter use (OR= 1.5, 95% CI of 0.58 – 3.9). There was also no association between the belief that diarrhea can be prevented and filter use, (OR= 1.12, 95% CI 0.37 – 3.34), using households who do not believe diarrhea can be prevented as the reference group. Of households using the filter, 66% reported that they checked its flow rate and 44% did not. However, there was no association between filter use and measuring flow rate (0.94, 95% CI of 0.08 – 10.5). Additionally, there was no association between filter use and cleaning the filter spout (OR=0.35, 95% CI 0.16 – 19.66). Experiencing a problem with the filter also was not associated with filter use (OR=0.35, 95% CI .065 – 1.86) if those reporting no problems were the reference group (325 households).

Filter Training

A factor households reported as a positive predictor of continued filter use was receiving training on operation and maintenance of the BSF with odds ratio of 2.04 and a 95% confidence interval of 1.06 – 3.93. This suggests that training in filter operation and use was strongly associated with filter use and statistically significant. Those families that reported receiving training were more likely to use the filter. Hence, receiving filter training can be an indicator of the household's ability to continue using the filter as was the use of a dipper to collect water from the storage container.

Container Cleaning

Another possible factor associated with filter use was whether the family cleaned the source water storage container, (OR=14.6, 95% CI 1.29 – 164.7). This confidence interval is wide and a possible artifact of a small control group size (3 households), therefore resulting in little power in the 95% interval. Nevertheless, the odds of the households are 14.6 more that they will use the filter rather than not use the filter if they clean the water storage container.

Water Treatment Frequency

Another positive association with filter use was the number of times the households treated their water. Those houses that treated the water always or often were more likely to use the filter (OR= 30.63, 95% CI 3.33-281). This association also shows a wide 95% interval and probably has little power due to a small control group. However, the 95% CI does not span the null, indication of an association.

Water Sources

The water sources that the households used in the rainy season were examined in relation to filter use by first grouping households according to reported use of any of the three main categories of sources: surface water (lakes, ponds, streams, rivers, canals, channels and shallow wells), deep wells (>10m) and rain water. Each water source group was collapsed into binary variables that were divided based on use or disuse of the filter at the time of follow up. Filter use was not associated with surface water (OR=.615 and the 95% CI= 0.32 - 1.8) nor was it associated with the use of rainwater (OR=1.89, 95% CI=0.59 – 2.37) as shown in the table below. However, using a deep well compared to using a source other than a deep well was positively associated with filter use as indicated by the odds ratio of 2.6 and 95% confidence interval of 1.27 – 5.4 which does not cross a null value of 1.0.

Water Source	BSF Users	BSF Non Users	Unadjusted Odds Ratio	95% Confidence Interval
1. Surface (Yes)	112	182	0.62	(0.32 - 1.8)
Other	21	21		
2. Deep Well (Yes)	142	152	2.63	(1.27 - 5.4)
Other	11	31		
3. Rain water (Yes)	207	87	1.89	(0.59 - 2.37)
Other	28	14		

Table 15 Odds ratios and confidence intervals for water sources

Province and Wealth/Assets

When examining the relationship between all provinces and water sources, Kandal province was associated with rainwater use when compared to all other provinces, (OR=2.37, 95% CI 1.07-5.27) and Kratie was associated with deep well use. Kratie BioSand filter households had the second highest rate of disuse (15 households, 36%) and were users primarily of deep wells. Filter disuse in Kratie also may be associated with the low level of wealth in households from that province and the distance from the implementing organization's program office, which may result in less access to program support resources and physical isolation in the rainy season due to flooding. Kratie is largely inaccessible by vehicle in the rainy season and was inaccessible for part of the study. When examining the association of filter use and assets (motorcycle, vehicle, electricity, housing material, floor material, and cows), the association was of borderline statistical significance (OR=1.3, 95% CI .98 – 1.7). The assets index was based on the summary of the presence or absence of the aforementioned assets. Furthermore, as the number of assets increased, the odds of using the filter also increased except for households reporting 4 assets (see table below). Therefore, the presence of increasing assets was weakly associated with filter use according to the calculated asset index.

Asset	Not using filter	Filter use	Total
0	9 (21%)	34 (79%)	43 (100%)
1	9 (14%)	54 (86%)	63 (100%)
2	15 (12%)	107 (88%)	122 (100%)
3	5 (6%)	77 (94%)	82 (100%)
4	4 (18%)	78 (82%)	82 (100%)
5	0 (0%)	4 (100%)	4 (100%)

Table 16 Comparison of assets between continued filter use and non-users

When adjusting for province and wealth, households were categorized in to groups based on their reported assets as poor, middle or wealthy. There was a weak association with wealth (OR=1.79, 95% CI .94 – 3.4) and filter use however as wealth increased, filter use also increased but was not statistically significant. Half of the households that are not using the filter come from the poor category. The effect of wealth is not associated with province.

When adjusting for time in use, Kratie shows in general that filter use decreases. Kratie also had the largest percentage of households categorized as poor and no households fell into the wealthy category from Kratie province.

Time in Use

Another possible association for filter disuse is the time since installation. CGA has been working in Kandal province since the start of their BSF program. Hagar started the BSF program in Kompong Thom and Kratie as part of the CIDA funded Phase I initiative. These locations have the largest number of filters and the filters that have been in use for the longest period of time. Filters included in this study have been in use for up to 8 (Kratie) and 6.5 years (Kandal) that were included in this study and both organizations began pilot projects prior to 2000. There is however, no strong association between time in use and filter use, (OR=0.99 and 95% CI .88-1.09) because the interval crosses the null value of 1.0.

Adequacy of Household Water

Most families reported that their treatment method always provided enough drinking water for the family (306 households, 91%). There were 28 households (8%) that reported the family often had enough, and 2 (0.5%) households reported that the treatment method they were using rarely or never produced sufficient drinking water for the family. The household groups were collapsed into those who reported always and often having sufficient drinking water from their method of treatment and those who rarely or never had sufficient drinking water from their treatment method. Using logistic regression, the odds ratio of filter use and sufficient drinking water was 0.365 and the 95% confidence interval was 0.18 - 0.74. This shows a negative association between availability of treated water based on quantity (always or enough versus rarely or never enough) and filter use, as the OR and its 95% CI is <1. Therefore, people are less likely to use the filter if they report not receiving sufficient drinking water from this treatment method. This suggests household disuse of the filter is associated with dissatisfaction with their current treatment method to produce sufficient drinking water for the family. Because the OR is <1.0 and the 95% CI is relatively narrow and does not cross the null value of 1.0, there seems to be a strong association between filter use as a means to obtain sufficient treated drinking water to meet household needs.

Other Treatment Methods

Among the 294 households using the filter, 162(48%) respondents reported using another treatment. Of these households, 156 (96%) reported boiling as a secondary method of treatment. Rarely households using the filters also treated their water by settling which was reported in only three households, using chlorine (reported by one household), and using a different filter method (one household). Boiling water as a treatment method has a negative association with filter use, (OR= 0.65, 95% CI 0.15 - 0.27), indicating that families boiling water as a treatment option are less likely to use the filter. In this analysis, the reference group was taken to be those households that use all other treatment methods, including boiling, which was collapse into one binomial group, of which the other to which it was compared was filter use. This comparison shows statistical significance because the OR was <1 and the 95% CI was narrow and did not cross the null value of 1.0.

When households were asked if they drink water directly from the untreated water container, or from the source, there was a good negative association, (OR= .302, 95%CI 0.16-0.58). Hence, households are less likely to drink untreated water directly from the container without treatment if they use the BioSand filter. These findings affirm the notion that filter use is associated with not drinking untreated water.

Results and Discussion: Longitudinal Study

Study Overview

Sample size calculations indicated that approximately 72 households should be included in each study group, based on 75% power, to detect a 25% difference in diarrheal disease. Therefore, the total number of households surveyed as part of the health impact evaluation and water quality should minimally include 160 households. The study recruited over 50 households from each group and organization to account for drop out rates and visited each household 5 times between January to June 2007. Houses were visited multiple times to account for temporal changes in both water quality and community diarrhea disease burdens. Data on diarrhea disease incidence for each family member was recorded based on a 7-day recall period. The assessment also included measurements of water quality (*E. coli*, turbidity and pH).

Study Participants and Households

Households that participated in the longitudinal study were from Kandal, Kompong Speu, Svay Rieng, Kompong Thom and Kratie provinces. Over 50 households were recruited from each organization's program sites as an intervention or control household. A total of 1365 individuals were part of the longitudinal study, and 53% of the total participants were female. Total household numbers (and percent of total) per province were: 75 (36%) from Kandal, 26 (13%) in Kompong Speu, 34 (16%) in Svay Rieng, 40 (19%) in Kompong Thom, and 32 (16%) in Kratie province. Respondents were asked detailed questions about water and hygiene practices, education and sanitation.

As shown in Table 17, 107 households using BioSand filters were recruited for the intervention group and 102 matched households that never had BioSand filters were recruited for the control group. Only 2 households were lost to follow up in the intervention group. A total of 722 individuals were in the intervention group. There were 373 (52%) females in this group, and a mean number of 6.75 individuals per household. The two groups include all ages. The level of education of household individuals ranged from no education to university level; some had taken additional training courses. The largest number education group was those who attended primary school or are receiving primary education. Ten individuals from the intervention group reported receiving a university level education.

The control group lacking a BSF consisted of 102 households recruited as matches to the intervention (BSF) households. There were 643 individuals in the control group and 356 (49%) were female. The mean number of individuals per household was 6.3. Education varied from none (189 individuals) to primary, high school and university level education; no one reported attending any additional training courses. Most individuals had received or were currently receiving primary education.

Characteristic	Intervention Group	Control Group
Total Households	105	102
Number of Households by province		
Kandal	36 (34%)	39 (38%)
Kompong Speu	13 (12%)	13 (13%)
Svay Rieng	17 (16%)	17 (17%)
Kompong Thom	20 (19%)	20 (20%)
Kratie	16 (15%)	16 (16%)
Households lost to follow up	2	1
Total number of people per group	722 (53%)	643 (47%)
Mean number of individuals per household	6.75	6.3
Number of females	366 (51%)	356 (49%)
Soap observed in house		
Yes	100 (95%)	96 (94%)
No	5 (5%)	5 (5%)
Reported receiving health education		
Yes	104 (99%)	96 (94%)
No	0 (0%)	5 (5%)
Covered water storage		
Yes	56 (53%)	48 (47%)
No	50 (47%)	55 (53%)
Wash hands with soap		
Yes	83 (79%)	54 (53%)
No	12 (11%)	49 (48%)
Drinking water source used in dry season		
Surface water	48 (47%)	51 (50%)
Deep well	48 (47%	44 (43%)
Rainwater	4 (4%)	2 (2%)
Observed method of drawing water		
Tap/pour	19 (18%)	29 (58%)
Dipper/cup/other instrument	67 (64%)	46 (45%)

Treatment method used by household		
BSF	105 (100%)	0 (0%)
Boil	71 (70%)	34 (33%)
Settling	1 (1%)	46 (45%)
Chlorine	1 (1%)	22 (22%)
Other filtration method	0 (0%)	14 (14%)
Formal Education		
0. Has not attended school	171 (24%)	189 (29%)
1. Primary school	313 (43%)	295 (46%)
2. High school	225 (31%)	158 (25%)
3. University	10 (1%)	1 (.2%)
4. Training Courses	3 (.4%)	0 (0%)

* - $p < 0.05$ (t-test or chi-squared test)
Table 17 Characteristics of longitudinal study households

Water Use and Handling Practices

As shown in Table 17, the variables for which data are presented for the longitudinal are from responses to similar questions that were asked in the cross-sectional survey. The respondents were asked questions regarding water use and handling practices during the observation period, which happened to be the dry season, between January and May, 2007. For intervention households, 48 (46%) reported using surface water as one of their sources, and 48 (46%) also reported using a deep well. Only 4 (1%) reported using rainwater as a dry season drinking water source. Many households used multiple sources. Surface water included shallow wells (<10m), rivers, lakes, ponds, streams and canals. Deep wells were considered >10m in depth. To access stored water in the home, 19 households reported using a tap or pouring water directly from the stored water container before drinking and 67 reported using a dipper or a cup to transfer water before drinking. No households reported using their hands as a method to collect drinking water from the storage container. Fifty-six (53% of 105 filter users) households reported covering their water storage container and 50 households from the intervention group (48%) did not.

Of the control household 51 (50%) reported using surface water, 44 (43%) used a deep well and only 2 (2% of the 102 households) reported using rainwater as a dry season drinking water source. To access stored water in the home, 29 (28%) households used a tap or poured the water directly from the storage container before drinking and 46 (45%) households reported using a dipper to transfer water before drinking. No households in the control group reported using their hands as a method to collect drinking water from the storage container. Covering the storage container was reported by 48 (47%) control households and 55 (53%) households reported that they did not cover the storage container.

The BSF treatment method was reported by all 105 (100%) of intervention households, which was an inclusion criterion for intervention households participating in the study. The second treatment method reported by intervention household respondents was boiling. The main treatment of water reported by control households as settling (46 households, 45%), followed by boiling (34 households, 33%), chlorination (22 households, 21%) and another filtration method (14, 13%) households.

Sanitation and Hygiene Practices

Of the intervention household, 83 (79%) reported washing their hands with soap, 12 (11%) households did not wash hands with soap. A total of 100 households (95%) reported having soap in the house and interviewers were able to observe soap presence at the time of visit. Of the 105 intervention households that were recruited for the longitudinal study, 104 (99%) reported receiving health education, mostly from the implementing organization (91 households, 87.5%). There were 59 (56%) intervention households reporting access to sanitation, and 46 intervention households (44%) reporting use of the ground, bushes, or a plastic bag as a place to defecate, which was also considered having no access to sanitation. Having access to sanitation was considered as having access to a toilet or latrine, or flush toilet, private or shared. These options were considered as having access to sanitation was collapsed into one category. No households had connection to a conventional sewerage system.

Control households reported that 54 (53%) washed their hands with soap and 49 (48%) did not. A total of 96 (94%) households were observed to have soap present at the time of the visit and only 5 (5%) households did not. Receiving health education was reported by 79 (78%) households and 24 (24%) reported never receiving health education. Access to sanitation was reported by 40 (38%) control households and 63 (62%) control households reported not having access to sanitation and defecation on the ground, in the bushes, or in a plastic bag.

Water Quality Analysis

Water samples were collected from each household that participated in the longitudinal study at the time of visit for interviews. The quality of untreated, treated and stored water was determined, based on microbial indicator organisms (total coliforms and *E. coli*) and the physical and chemical parameters of pH and turbidity. The World Health Organization categorizes drinking water quality into risk categories according to concentrations of *E. coli*/100ml. Low risk is considered none and 1-10 *E. coli*/100ml, intermediate risk is 11–100 *E. coli* /ml, and high risk as 101-1000 *E. coli*/100ml (WHO 2003). As shown in Table 4.5.1, 335 (44%) of untreated (raw) water samples had 100-1000 *E. coli* per 100ml and 266 samples (35%) had *E. coli* concentrations over 1000 *E. coli*/100ml, which gives a high risk total of 79% of samples. For households using the filter, 402 samples (55%) had treated water between 1-10 *E. coli* per 100ml and 28 samples (3.8%) has no *E. coli*/100 ml, which is considered low risk by the WHO. BSF households has 184 treated water samples (25%) at the intermediate risk level of 100-1000 *E. coli*/100ml) and 122 samples (17%) at the risk level of >1000 *E. coli*/100 ml. However, samples of stored water for drinking were on average and on the basis of percentage of samples in categories of *E. coli* risk levels, higher than in the filtered water. The percentage of water samples from BSF households that were in the low risk category of 10 or fewer *E. coli* per 100 ml were <7% untreated, 59% treated and 22% stored.

For control households, 198 raw samples (68%) were in the high risk categories having >100 *E. coli*/100 ml. Stored water was on average even worse quality, with 400 samples (77%) having >100 *E. coli*/100 ml, of which the vast majority (336 samples or 72%) had concentrations of >1000/100ml.

Number (percentage) of all samples by *E. coli* concentration of household drinking water					
All	**<1**	**1 – 10**	**10 – 100**	**100 – 1000**	**>1000**
Untreated	63 (8%)	40 (5%)	60 (8%)	335 (44%)	266 (35%)
Treated	28 (2%)	402 (32%)	184 (15%)	72 (6%)	555 (45%)
Stored	14 (1%)	229 (19%)	220 (18%)	178 (14%)	600 (48%)
Intervention					
Untreated	3 (1%)	30 (6%)	45 (9%)	265 (53%)	153 (31%)
Treated	28 (4%)	402 (55%)	184 (25%)	72 (10%)	50 (7%)
Stored	10 (1%)	157 (21%)	181 (25%)	154 (21%)	234 (32%)
Control					
Untreated	60 (22%)	10 (4%)	15 (6%)	70 (26%)	113 (42%)
Treated	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Stored	4 (1%)	72 (14%)	39 (8%)	24 (5%)	366 (73%)

Table 18 Number (percentage) of all samples by *E. coli* concentration of household drinking water

Water Quality Data Arithmetic and Geometric Means All Samples	Total Coliforms (Arithmetic)	Total Coliforms (Geometric)	*E.coli/100ml* (Arithmetic)	*E.coli/100ml* (Geometric)	Turbidity (NTU)
Untreated	16886	3162	4322	251	12
Treated	2085	112	394	8.3	2.6
Stored	5765	891	1473	40	3.4

Table 19 Water quality data, arithmetic and geometric means, all samples

As shown in the table above, untreated water had mean concentrations of 16886 total coliforms, 4322 *E. coli*/100ml and 12 NTU. Concentrations of these analytes treated water (of intervention and control households) are lower than untreated water, with mean total coliforms, *E. coli* and turbidity of 2085/100 ml, 394/100 ml and 2.6 NTU, respectively. Levels of these analytes increase again in stored water, with mean total coliforms, *E. coli*, and turbidity of 5765, 1473 and 3.4, respectively. However the levels of these analytes are lower in stored water than the untreated water.

Sample Group	Intervention	Control
Untreated Total coliform Observations	734	496
Log10 Geometric mean	3.4	3.6
Standard Deviation	0.9	0.8
Treated Total coliform Observations	708	No data
Log10 Geometric mean	2.1	No data
Standard Deviation	1	No data
Stored Total Coliforms Observations	589	147
Log10 Geometric Mean	3.1	2.2
Standard Deviation	0.9	1.3

Table 20 Log_{10} Geometric mean concentrations for sample groups

Sample Group	Intervention	Control
Untreated E. coli avg.		
Observations	734	445
Log10 Geometric mean	2.2	2.6
Standard Deviation	1.2	0.9
Treated E. coli avg.		
Observations	707	No data
Log10 Geometric mean	0.9	No data
Standard Deviation	1	No data
Stored E. coli avg.		
Observations	588	147
Log10 Geometric Mean	1.7	1.1
Standard Deviation	1.2	1.1

Table 21 *E. coli* average concentration for sample groups

The table above shows that the average concentration of *E. coli* is lower in treated water (0.92 $\log_{10}$/100 ml) then in untreated water (2.2 $\log_{10}$ *E. coli*/100 ml) of intervention households, by about 1.3 $\log_{10}$ or 95%. However, the average concentrations of *E. coli*. are higher in stored water (1.7 $\log_{10}$/100 ml) than in treated water, but still lower than in the untreated water (2.2 $\log_{10}$/100 ml). There are several possible reasons for increased levels of indicator bacteria in stored water that has been treated, including post-treatment fecal contamination of the water by users or growth (propagation) of the *E. coli* still present in the treated water(Wright et al., 2004). The concentration of *E. coli* in untreated water for control households (2.6 $\log_{10}$/100ml) is also slightly higher than in intervention households (2.24 $\log_{10}$). Stored water *E. coli* concentration is higher in intervention households (1.7log $_{10}$)

versus control households ($1.1\log_{10}$). This suggests that intervention households are susceptible to recontamination.

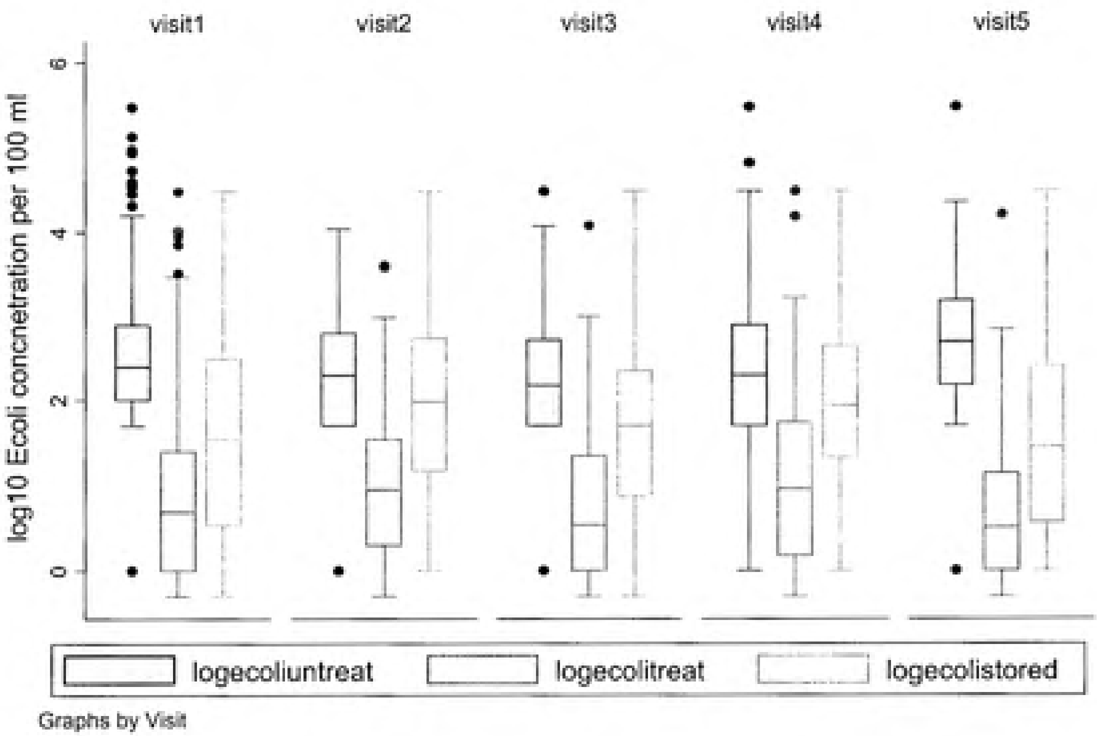
Type of comparison	Log_{10} reduction Total Coliforms	Log_{10} reduction *E. coli*	Turbidity % reduction
Untreated to Treated	1.3	1.3	82%
Treated to Stored	-1	-0.8	7%
Untreated to Stored	0.3	0.5	80%

Table 22 Geometric mean reductions by the BioSand water filter during longitudinal study

Table 23 below shows the comparison of geometric ($\log_{10}$) means of BSF samples and controls. All of the test were unpaired t-tests and compared *E. coli* concentration in BSF and control households. As shown in the table below, all of the tests were statistically significant and demonstrated significantly different concentrations of *E. coli* for the various samples that were compared. The test that was not significantly different was for the BSF treated and stored and the control stored/treated suggesting that water directly from the BSF has the same concentration of *E. coli* as water treated and stored in control households. Other significant tests to note are: untreated water in BSF and control households, stored, treated water in BSF and control households and BSF treated vs. stored treated BSF water. The BSF untreated water was slightly less contaminated than the control untreated water. The result shows that the water that is stored from the BSF is getting contaminated. And stored water from the BSF is more contaminated than the water coming directly from the BSF (treated). The stored water from the BSF households is more contaminated than the stored treated water from the control households.

	BSF Treated	BSF Treated and Stored	Control Untreated	Control Stored
BSF Untreated	P<0.0001	P<0.0001	P=0.009	P<0.0001
BSF Treated	-	-	P<0.0001	P=0.07
BSF Treated and Stored	-	-	P<0.0001	P<0.0001
Control Untreated	-	-	-	P<0.0001
Control Stored/Untreated	-	-	-	-

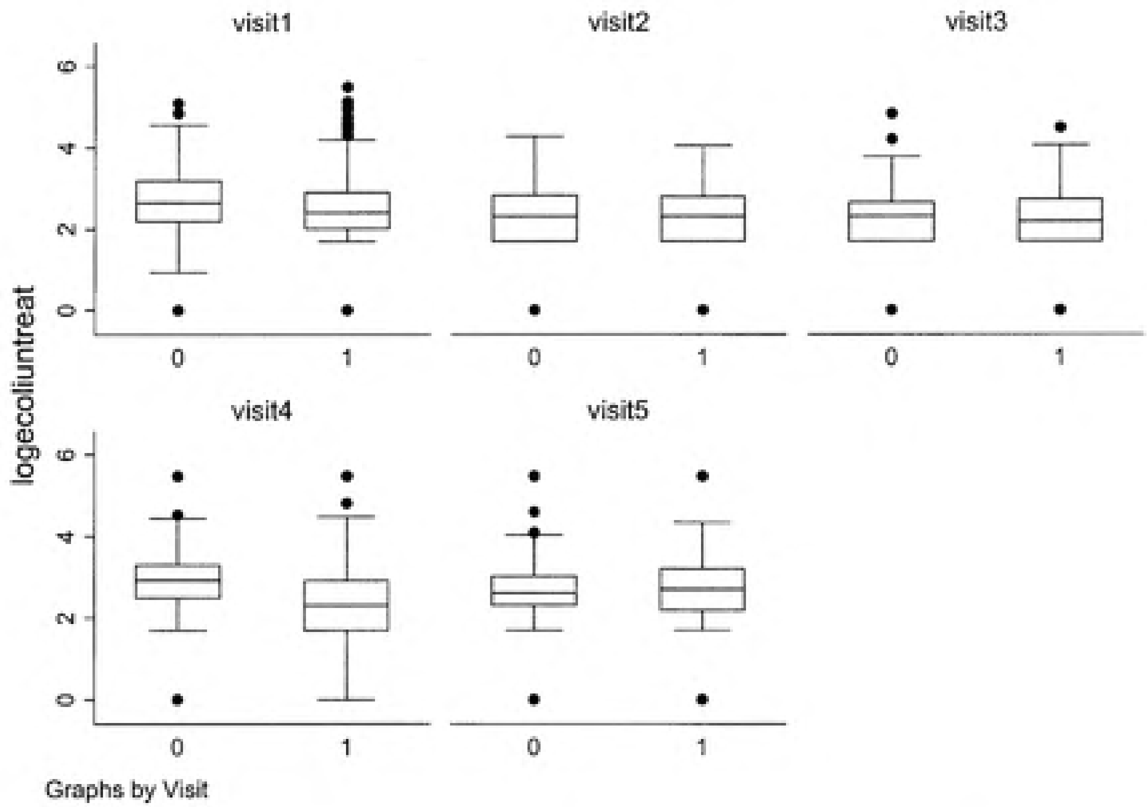
Table 23 Statistical comparison of geometric means of BSF and control water samples



Graph 2 Log_{10} concentrations of *E. coli* in the 3 types of household water samples per household visit

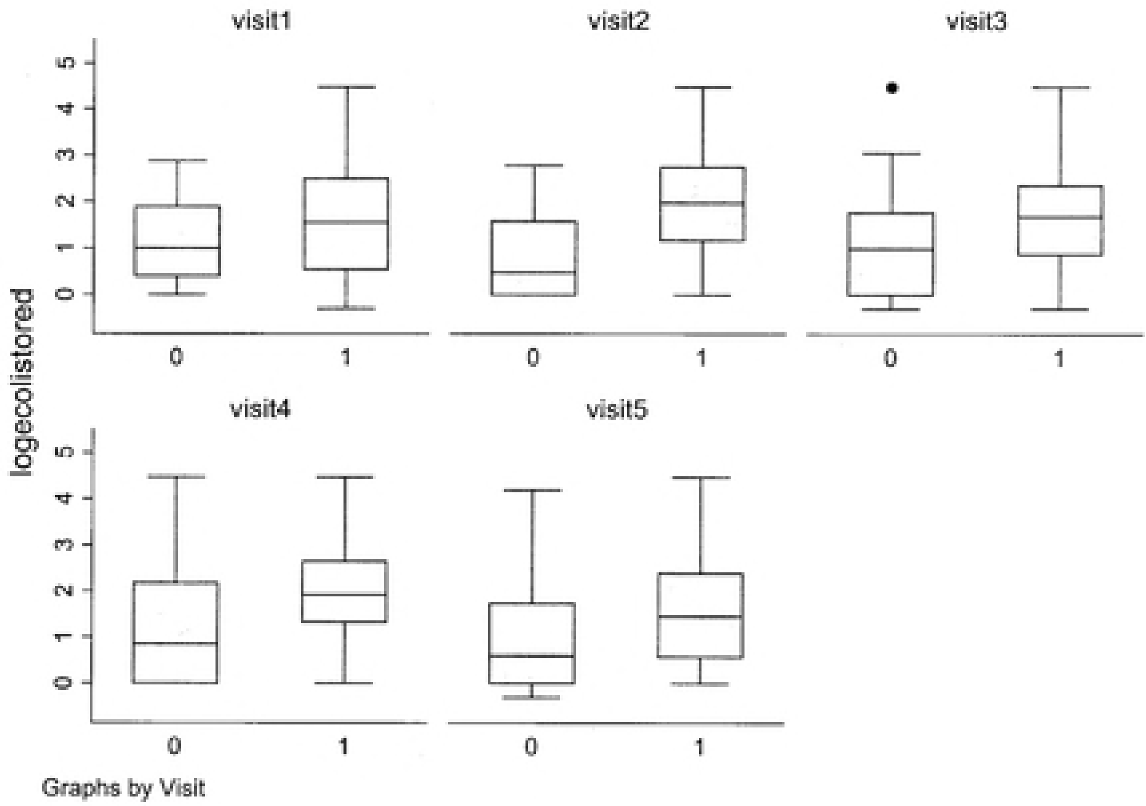
The graph above present box-and-whisker plots of the $\log_{10}$ *E. coli* concentration per 100ml in the three types of water, samples, untreated, treated and stored, from 5 successive household visits during the longitudinal study. There is a general pattern of average $\log_{10}$ *E.*

coli concentration being highest in untreated water, lowest in treated water and in between these two in stored water. The concentration ranges of *E. coli* in raw and treated water do not overlap, however there is overlap of *E. coli* concentration ranges between treated and stored water and between raw and stored water.



Graph 3 Comparison of untreated water samples of BSF and control households by visit

The graph above compares the untreated water samples from the BSF and the control households by visit. Based on the t-test they are statistically different however, the box and whisker plots do not suggest there is a difference between them because the ranges and the medians are similar. The graph below compares the stored samples from the BSF and the control households. The t-test showed that the samples were statistically different and the graph also reflects the differences because the means are not similar and the ranges are also visibly different.



Graph 4 Comparison of stored water samples from BSF and control households by visit

Log10 reduction of *E. coli*	Intervention	Control
Untreated – treated		
Observations	707	No data
Mean	1.3	No data
Standard deviation	1.43	No data
Minimum	-3.9	No data
Maximum	5.5	No data
Untreated – stored		
Observations	587	147
Mean	0.5	1.9
Standard deviation	1.6	1.6
Min	-4.5	-3
Max	4.4	5.2
Treated – Stored		
Observations	585	No data
Mean	-0.8	No data
Standard deviation	1.3	No data
Min	-4.8	No data
Max	2.9	No data

Table 24 Log reduction values of *E. coli* based on concentrations in untreated water samples and either treated or stored water samples

The mean $\log_{10}$ *E. coli* reduction value is 1.31 based on 707 sets treated and untreated water samples collected over 5 visits between January-May, 2007. The corresponding mean $\log_{10}$ *E. coli* reduction from untreated and stored water is 0.51. The mean $\log_{10}$ *E. coli* concentration difference between treated water and stored water is -0.8, which indicates higher levels of *E. coli* in the stored water than in the treated water. In order to test for statistical significance, $\log_{10}$ *E. coli* concentrations of untreated and treated water samples were compared using a two sample mean test at an alpha level of .05 (α=.05). At a p value of <0.000, the means were statistically different and the confidence intervals did not overlap. When comparing $\log_{10}$ *E. coli* concentrations of untreated and stored water, the intervals did not overlap and the means were also significantly different at α=.05, with a p value = 0.000. The treated versus stored two sample mean test of $\log_{10}$ *E. coli* concentrations also showed statistical significance and no confidence interval overlap. Overall, the log *E. coli* reductions by the filter are statistically significant, so the filter is apparently functioning to reduce *E. coli* levels in water. However, *E. coli* concentrations become significantly elevated again when the treated water is stored, although the concentrations remain significantly below those in the untreated water.

When water samples taken from the filter (treated) are compared to water samples of the untreated water taken at the same time, the comparisons of concentrations of a constituent like *E. coli* between the two samples are not necessarily indicative of the actual performance of the filter in reducing the contaminant. One reason for this may be because these are grab samples collected at one point in time and therefore are not necessarily representative of filtrate water produced at other times of the day or on other days. In addition the filtrate water may not be from the same batch of untreated water collected at the same time. The filtrate may actually be representative of untreated water that was applied the previous day. This is because the design of the filter requires the user to pour (dose) a water volume of greater than 18L into the top of the filter to displace the 18-liter retained volume in the filter bed from previous dosings, before being able to take a sample of effluent water corresponding the water being poured into the filter at a given time. Water in the filter bed from the previous doing is displaced by the water initially being poured into the filter. The first 18 liters of water in the filter that is displaced by the water being poured into the filter is from the previous dosing. If a complete pour into the filter is less than 18 liters, it does not fully displace the volume of water held in the filter bed from the previous dose. Therefore, the concentrations of fecal indicator bacteria and other constituents in the first 18 liters or less of collected filtrate are indicative of the change in concentration relative to the water applied to the filter from the previous dose. However, the observation of generally consistent patterns of difference in *E. coli* concentrations between untreated (dosed) and treated (filtrate) water from the 5 different sampling times suggests that these data are generally representative of filter performance, even though the filtrate water does not correspond to the untreated water that was dosed to the filter that day. Because of this situation, it is also possible for a sample of untreated water applied to the filter to be better quality than the filtrate water collected at the same time. This can result is a comparison of the *E. coli* concentration in the filtrate and the untreated water giving an apparent negative reduction (a negative $\log_{10}$ reduction when subtracting the $\log_{10}$ *E. coli* concentration of the filtrate from the $\log_{10}$ *E. coli* concentration of the untreated water). However, examination of average concentrations of constituents such as *E. coli* is informative because performance is generally gauged through the calculation of $\log_{10}$ reduction values (LRVs) based on repeated analyses of a series of samples collected over time.

Number (percentage) of sample pairs in decimal categories of E. coli log_{10} reduction values (LRV) (untreated minus treated water) N=737	<0	0 - 0.99	1 - 1.99	2 – 2.99	3 - 3.99
Untreated – treated	118 (16%)	132 (18%)	199 (27%)	196 (27%)	54 (7.3%)
Untreated – stored	197 (27%)	145 (20%)	127 (17%)	91 (12%)	26 (3.5%)
Treated – stored	400 (54%)	148 (20%)	30 (4.1%)	7 (0.95%)	0 (0%)

Table 25 Number (percentage) of sample pairs in decimal categories of *E. coli* log_{10} reduction

As shown in Table 25, most of the log_{10} *E. coli* reductions based on the concentration differences between untreated and treated water are between 1 to 3 log_{10} (54%), with much smaller percentages of LRVs either higher or lower than this range. Small percentages of LRVs (16%) are below 0 log_{10} and therefore a negative value. These are sample pairs for which the log_{10} *E. coli* concentration on the treated water is higher than in the untreated water and could be caused by temporal differences in the water applied to the filter and the filtrate, as previously noted.

The percentages of samples in decimal ranges of log_{10} *E. coli* reductions based on log_{10} concentration differences between untreated and stored water are distributed more uniformly over the entire range of decimal categories. For 197 sample pair LRVs (27%) the difference between untreated and stored water is a negative LRV value, due to higher levels of bacteria in the stored water than in untreated water.

The decimal categories of log_{10} *E. coli* reductions from treated to stored water show that more than half of the values (400 samples, 54%) are negative, indicating more *E. coli* in the stored water than the treated water and therefore suggesting recontamination or *E. coli* growth. Of the remaining LRVs, most (20%) are in the 0-1 category or the >4 category. The reasons for this wide range of difference in LRV performance are unknown.

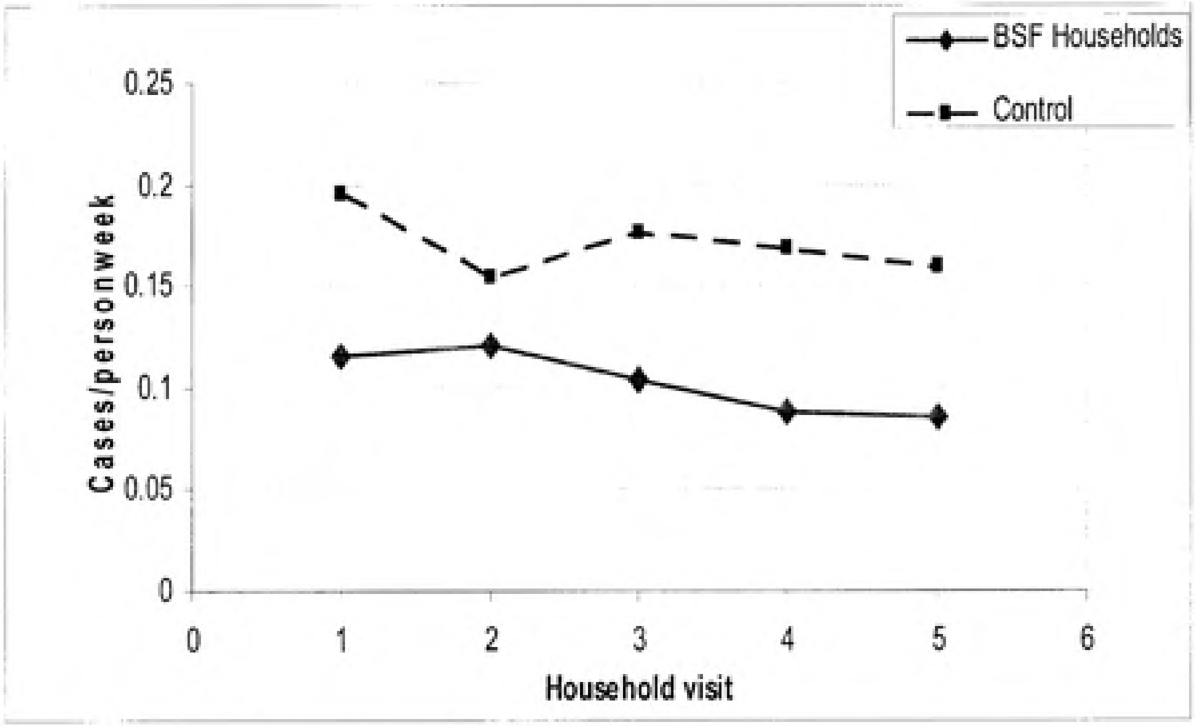
Brown and Sobsey have suggested that LRVs alone may be misleading. This is because filter effluent samples (treated water) could have low or no detectable *E. coli* in the 100ml samples, but still give low calculated LRVs due to no or low *E. coli* concentrations in the untreated water. The performance of the filter could be underestimated because the LRV is a function of both the influent concentration and the effluent concentration. If there is no *E. coli* detected in the untreated water, the treated water or both, the actual values for *E. coli* concentrations are indeterminate and censored. Therefore an uncensored or discrete LRV can not be calculated to accurately document the ability of the filter in reducing the indicator concentration. It is also possible for *E. coli* to grow in stored water and in storage vessels, which can also lead to underestimates of the ability of the filter to reduce *E. coli* and produce filtered water having low *E. coli* concentrations. In order to reduce post-filtration fecal contamination, a container with a tap or a narrow opening discourages other objects from being placed into the treated water. The extent of *E. coli* growth that may have occurred in stored water and in the storage containers or the extent of treated and stored water fecal recontamination related other sources of feces are unknown.

Negative $\log_{10}$ *E. coli* reduction values for the difference between untreated and treated water could be due to higher levels of these bacteria going into the filter from raw water sources that are not the same as the raw water sampled on the day the filtrate was sampled. There may also be high levels of *E. coli* in the biofilm (schmutsdecke) of the filter from previously applied water having high *E. coli* levels, which could lead to the passage of *E. coli* through the filter and into the filter effluent water. Sources of these *E. coli* could be the raw water itself. *E. coli* contamination of a biofilm in the raw water containers and improper (unsanitary) water handling practices. As previously noted the volume of water that has passed through the filter and sampled may not be sufficient to displace the volume of water inside the filter bed. Hence, sampling from the effluent water is not actually indicative of the current quality of water being applied to the filter and being tested for quality. A difference in the source water applied to the filter from one day to the next can also produce different contaminant reduction results. If the household uses well water one day and switches to a different source another day, water quality of the effluent can also be affected. The extent of regrowth of indicator bacteria in untreated and stored water may also make it difficult to compute reliable and accurate LRVs.

E. coli contamination of water can also occur if the components of the filter that come into contact with effluent water are contaminated. The spout can be a source of contamination if not properly cleaned. From the cross sectional survey, respondents were asked if the household cleaned the spout. Of those using the filter, most households reported cleaning the filter spout within a month from the time of visit (76%) but the other respondents could not remember when the filter spout was last cleaned or they reported never cleaning the spout. Accessibility of the filter to animals, children and other environmental contamination can also be the cause for recontamination, as can be improper handling of storage containers and improper cleaning procedures.

Diarrheal Illness

Subjects who participated in the longitudinal study were also surveyed for diarrheal illness. As previously stated, diarrhea was defined as three loose or watery stools within a 24 hour period or any stool with blood in it during a 24 hour period. Households were visited between January and May 2007 (dry season) and reported on the cases of diarrhea from household members within the past 7 days (7-day recall period). Diarrhea data was collected over five visits to each household in the study. Rates of diarrheal disease in each group were calculated based on the seven day period and confirmed cases. The cases of diarrhea per person-week for each group are listed in Table 26. The rates of diarrhea for the intervention households were always lower than the rates for the control households over the course of the study. Overall each group experienced declining rates over the 5 month period however in visit 2 there was a slight increase in reported cases from BSF households though not evident from the table reporting cases per person-week due to rounding. This may be attributed to a change in seasons since the first visit was conducted in January the end of the rainy season and the second visit was in February which was part of the dry season or possibly over-reporting. There was a decrease in rates in control households for visit 2 which could have been related to transition from rainy to dry season conditions or possibly under-reporting. For BSF households, the range of cases per person-week was between 0.09-0.12. The range for control households was between 0.15 - 0.20.



Graph 5 Diarrhea by group per visit

Household visit	BSF Households	Control Households
1	0.12	0.20
2	0.12	0.15
3	0.10	0.18
4	0.09	0.17
5	0.09	0.16

Table 26 Cases of diarrhea per person week by group and visit

Statistical Analysis of Diarrhea Rates in Relation to Other Variables and Conditions

As summarized in Table 26, there is a clear association between those who use the BioSand filter and reduced cases of diarrhea (OR=0.56, 95% CI 0.49-0.66). The households that reported using the filter had 44% less diarrhea cases than households that did not have a filter. The protective effect of the filter on diarrhea risk was shown in households using the filter across all age groups, sexes, and provinces. An exception is the age group of 0-2 years, which when adjusted from the group that originally included all children <5 did not experience a significant protective effect, as further explained below.

Group	Odds Ratio (OR)	Confidence Interval (95% CI)
All ages		
<5	0.68	0.54 – 0.85
5-14	0.54	0.37 - 0.77
15>	0.49	0.38 - 0.62
Age Adjusted		
0-2	0.89	0.63 - 1.24
2-5	0.56	0.42 – 0.76
5>	0.54	0.41 - 0.60
All ages	0.56	0.49 – 0.66
Adjusted (0-5, 5-14, 15>)	0.58	0.50 - 0.58
Age Adjusted (0-2, 2-4, 5>)	0.57	0.49 – 0.66
Sex		
Male	0.53	0.43 - 0.66
Female	0.58	0.40 - 0.60
Province		
Kandal	0.62	0.49 - 0.78
Kompong Speu	0.59	0.39 – 0.88
Svay Rieng	0.41	0.28 - 0.61
Kompong Thom	0.69	0.50 – 0.94
Kratie	0.48	0.34 - 0.68

Table 27 Stratified odds ratios and confidence intervals for diarrheal disease (filter as referent group)

Independent associations between diarrheal disease and other measured cofactors were analyzed and displayed in Table 27. Households were first grouped according to age, with the age categories of 0-5 years, 5-14 years, and 15 years and older, based on age at the time of the first household visit. Most diarrhea cases occurred in younger children and therefore an effort was made to estimate diarrhea disease risks as odds ratios for the years when rates of diarrhea would be most impacted in filter households. As shown in Table 27, adjusting for age showed a decreased but still protective effect on diarrhea as odds ratios, compared to unadjusted values. The greatest diarrhea disease reduction (protection) by the filter was found in the group of 2-5 years of age, with 46% less diarrhea than in controls (non BSF households), when adjusted for age. Age was adjusted and stratified by cohorts of ages 0-2, 2-4, 5 and older. There remained a strong association between reduced cases (risk) of diarrhea in filter households (OR=0.58, 95%CI 0.50-0.58) compared to non-filter households.

The adjusted age cohort of 0 and 2 year olds suggests there was not a strong association with filter use and decreased diarrheal illness (OR=0.89). This cohort shows the highest rates of diarrhea yet the data also suggests that they were the most unaffected by filter use. They did not seem to be significantly protected by the filter and the confidence interval was statistically not significant and spanned the null value of 1 (95% C.I.=0.63-1.24). It is possible that children in this age group are not exposed to filtered water because they are being fed breast milk or they may be receiving boiled water as their source of drinking water, when it is used to make powdered formula.

The group most significantly protected by the filter on the basis of the greatest reduction of diarrheal illness was the cohort of 2-4 years of age, after age adjustment. This protective effect may be due to this age group being exposed to untreated water and the filter intervention being able to greatly improve water quality and reduce waterborne pathogen exposures, consequently reducing diarrheal illness. This age group is also able to walk and increased exposure to other diarrheal disease causing agents may increase with increased mobility and therefore a protective effect was identified (OR=0.56, 95% C.I.=0.42-0.76). The age group of 5 and older also showed significant association between filter use and reduced cases of diarrhea. There were also more observations in this age category. There was little change in diarrheal illness between the categories of age 5-15 and 15 and older therefore, these groups were categorized under one group (>5 years). For this age group the OR was 0.54, with a 95% CI of 0.41 – 0.6.

There was also association of filter use with reduced diarrheal disease risks for both male subjects (OR = 0.53, 95% CI = 0.43-0.66; 3252 observations) and female subjects (OR = 0.58, 95% CI = 0.4 – 0.6; 3662 observations) and reduced cases of diarrhea. A positive association of filter use with reduced diarrhea disease risk was also found for filter households of all provinces. The magnitude of the association of reduced diarrhea risk with filter use varied among the provinces but all ORs were <1 as were their 95% CIs. The numbers of observations in each province were high, which probably helps document the protective effect of BioSand filter use on diarrhea risk: Kandal (2843), Kompong Speu (858), Svay Rieng (915), Kompong Thom (1165), and Kratie (1113). The province with the greatest reduction, or the lowest odds ratio was Svay Rieng and the province with the lowest reduction was Kompong Thom. All of the confidence intervals overlap so there appears to be no significant difference between the provinces.

Chapter V

Discussion

Cross-sectional study

One of the purposes of the study was to assess the sustainability of the BioSand filter and its uptake in households from Hagar and CGA project sites. As determined in this study, there was a high rate of filter use, 87.5% of households who received a filter were still using it, some households up to 8 years since implementation. These results suggest the BioSand filter is a sustainable and robust point of use water treatment technology.

The BioSand filter also had high uptake by users because it is not affected by breakage or the need for replacement parts or other requirements to help it function such as electricity or chemical additives. The BioSand filter is also difficult to move or transfer because of its weight which reduces opportunities to compromise the body of the filter and is less prone to damage from daily use. The materials to make the filter are locally found and all filter components are available locally and are durable for a lifetime of use. Training on the operation and maintenance of the filter was shown to have strong association with filter use. NGO's and other implementers who reinforce implementation by using developed software and education for behavior modification also increased the likelihood of filter use.

The results of the cross-sectional statistical analysis section of the study suggest that the BioSand water filters are more likely to be used in households who: (1) reported receiving training on the operation and maintenance of the filter (2), use a dipper or other item to draw drinking water from the storage container (3), clean their storage container (4), always or often treat the water (5), and use a deep well. Factors associated with filter disuse were: (1) boiling drinking water as a method of treatment (2), not receiving sufficient drinking water from the current treatment method (3), and households are less likely to drink untreated water directly from the container without treatment if the household uses a BSF. There was no association with using surface water or rainwater, access to sanitation or hygiene practices, or wealth and assets and filter use.

The use of deep wells and association with filter use may be related to the perception of high arsenic levels in groundwater. Kratie province had the second highest number of filters not being used but also had the filter that had been in use the longest. Kratie was also associated with deep well use and when adjusted for time, filter use decreased. Kratie province also had the lowest level of wealth and reported fewest assets and no households categorized as wealthy.

A possible reason for disuse of the filter in the provinces during the rainy season may be that people perceive the quality of rainwater to be higher and therefore do not filter their water. The availability of rainwater in the rainy season may also lead households to stop using the filter because of the perceived quality and the quantity available during the season. Households may choose to stop using the filter because it may save time and effort over having to collect water and filter it.

In comparison with the ceramic water purifiers distributed in Cambodia, results from the independent appraisal conducted in 2006 show that the ceramic filters are more likely to be used in households that have knowledge of safe water, sanitation and hygiene practices, purchase the technology, use surface water sources for drinking water and who do not use deep wells. The ceramic filters were disused because of high rates of breakage and the need for replacement parts. There was also a 2% rate of disuse each month after installation and the average time in use was about 2 years. The BioSand filter does not show the same rate of disuse that the ceramic filters have shown because they are not prone to breakage.

From findings in published peer-reviewed literature, there is evidence that a major limiting factor to success of household water treatment technologies is the uptake rate. The declining use rate of 2% in the independent appraisal of the ceramic filters in Cambodia were consistent with the findings of one other ceramic filter implementation study that reported a decline in use of approximately 20% after 9 months in Bolivia in the absence of replacement filters (Clasen et al., 2006). Other published, peer-reviewed literature shows evidence that uptake rates limit success of household water treatment is demonstrated by PUR, a disinfectant/coagulant chemical treatment product. PUR reported repurchase proportions of 5-13% in test markets in Guatemala, the Philippines, and Pakistan (Allgood 2005). As also mentioned by Brown and Sobsey, 2006, unpublished data on solar water disinfection method using PET bottles from Bolivia indicated that household use of the method had fallen to 25% within the first year.

The systematic review conducted by Arnold et al. that measured the health impact on water quality of point of use chlorine drinking water treatment, showed a major finding that nearly all trials on the topic have been short (median length was 30 weeks. Although not statistically significant, they observed an attenuation of the intervention's reduction of childhood diarrhea in longer trials. They suggest studies with multi-year follow up to assess long term acceptability and sustainability of health impacts shown by the shorter trials identified in the review. Although the technologies are different, the BSF study conducted in

Cambodia is an initial assessment of long term acceptability and sustainability which was proven to be successful in Cambodia compared to other interventions. Continued evaluation of the sustained health impact should be conducted as a follow up to the results found in this study.

Chapter VI

Discussion

Longitudinal Prospective Cohort study

The research shows that using a BSF can improve the microbiological quality of drinking at the household level compared to matched control households not using the filter. There was an average 1.3 log reduction of *E. coli* (95%) in households using the filter compared to control households. Using the BSF is also associated with reducing diarrheal disease by 44% in intervention households compared to households not using the BSF (unadjusted odds ratio). There was little dissimilarity between the control and the BSF groups which demonstrates that the comparison was appropriate and study results were comparable. There was a difference between the two groups as to whether or not they reported washing their hands with soap. The group using the BSF (intervention) reported 83 households (79%) washed their hands with soap and 12 households (11%) did not, however, the control (non BSF users) only 54 households (53%) washed their hands with soap and 49 households (48%) did not. These results suggest that there may be self selection in the group that uses the BSF. It is possible that households that have knowledge and increased awareness regarding water treatment may also be more likely to practice other hygiene and sanitation measures than households that do not. People who would choose to treat their water may be more prone to also washing their hands.

The age group most impacted by the intervention was the group of 2-4 year olds for the reduction of diarrhea. For the age group of 0-2, there was no strong association with filter use and reduced diarrheal illness which may be due to limited or no exposure to water from the filter as opposed to the age cohort of 2-4 year olds who have exposure to filtered water but also have increased exposure to untreated water and increased mobility which may increase exposure and risk to diarrheal disease. Mothers may still be breastfeeding or boiling water to mix with powdered formula for babies (age 0-2).

In comparison to other studies also measuring health impact by reduce diarrheal disease, the reduction of diarrhea is similar to the ceramic filters that showed a 46% reduction of diarrhea cases. The quasi randomized controlled trial of the BSF in the Dominican Republic, there was a 47% reduction of diarrheal disease rates for households using the BSF. Currently there are three review papers that document both improved drinking water quality and reduced diarrheal disease by the use of chlorine disinfection, combined chemical-coagulation and chlorine disinfection, solar disinfection and ceramic filtration. The average reduction in diarrheal disease measured from these studies ranges from 30-40% (Arnold & Colford, 2007; T. Clasen, Roberts et al., 2006; L. Fewtrell & Colford, 2004). The results from the evaluation of the BSF in Cambodia are consistent with those from the existing literature on the health impacts of household water treatment technology interventions and suggest the BSF is a promising candidate household water treatment technology in the effort to reduce the burden of diarrheal diseases globally.

The research from the BSF evaluation in Cambodia also demonstrates that the filter is able to remove up to 4 logs of *E. coli* bacteria however most $\log_{10}$ reductions are between 1 and 3 logs of *E. coli* concentration and the average reduction of *E. coli* was 95% overall. The ceramic water filter independent appraisal showed similar reductions of *E. coli* (95.1%) in treated versus untreated household water. However, both studies show that stored treated water is subject to recontamination. Although the BSF may not achieve the same level of indicator organism removal as other technologies, both the ceramic and BSF technologies show reduction of diarrhea in intervention households.

The overall moderate reduction of *E. coli* and reduction of diarrhea may be attributed to the continued use of the filter over time, and the higher rates of uptake of the BSF. Reductions may be associated with longer use and exposure to the filtered water or perhaps that households that have a filter will use it more often or always for drinking water. The proper use and maintenance of the filter and the education (software) programming is important to the ongoing effectiveness of the filter and decreasing the risk of waterborne diarrheal disease.

Chapter VII

Conclusions

The BioSand filter is a robust water treatment technology for use in rural Cambodian households and is capable of effective removal of indicator bacteria, specifically *E. coli* and improves the microbiological quality of drinking water. The reduction of diarrheal disease in households using the filter has also demonstrated that the filter intervention is comparable to other household point of use interventions. Moreover the BSF when compared to the ceramic filters has higher sustainability because the BSF does not break and has a lifespan much longer than the ceramic filters. The ceramic filter use was highly affected by high breakage rates and the need for replacement of parts which the BSF is not vulnerable to. The BSF produced similar reductions of *E. coli* and reduction in diarrheal disease to the ceramic filter however, the BSF showed a much higher uptake rate. Recontamination of stored however remains a challenge to maintaining safe drinking water quality at the household level.

Similar to the need for more research and program evaluation highlighted by the Ceramic Water Purifier study, there is need for more rigorous research on the health impact of the BSF and other household water treatment technologies through randomized controlled trials and rigorous epidemiological studies. More studies that critically evaluate environmental interventions and programs, both for health impact and economic sustainability are needed as well as efforts to critically examination implementation models, education strategies and cost benefit analyses. Besides health benefits, there are economic advantages to using the BioSand Water Filter and other household water treatment technologies. While scaling up is critical in contributing to the MDGs by providing access to safe water, critical program evaluation can ensure that interventions are working to protect users from waterborne disease (Brown and Sobsey, 2006).

The results from this study show that the BioSand Water Filter's demonstrated long term use, effectiveness in improving water quality and health, over a wide range of conditions, makes it one of the best household water treatment options available in Cambodia and developing countries.

APPENDIX A

Sample Size and Power Calculations for Prospective Cohort Study of BioSand Filter (intervention) and Matched Non-BioSand Filter (Reference/Control) Households in Cambodia

Sample size

Effect measurement will be the proportion of people in the intervention (BSF) versus reference/control (no BSF) groups who reported diarrhea in the preceding 7 days. The sample size for the study was computed as 421 individuals (in each group) to detect a 25% difference in proportions (RR=0.75) between the study groups with 75% power and $\alpha = 0.05$, using the methods for analysis of binary outcomes in multiple groups with repeated observations as described by Diggle et al. (2002). Calculations account for limited clustering within households and clustering in individuals over time, which are potentially important in the analysis of diarrheal disease data (Leon 2004; Killip et al. 2004). Results of power analyses in EpiSheet and EpiInfo were in general agreement with these results.

Because the average household size in the region is greater than 5.8 individuals, this is approximately equal to 72-73 households. Eightly (80) households will be recruited for each study group. These households will be visited 4 times each. Details from the calculations are shown below, along with other supporting documentation

Calculation Output

Analysis between groups, multiple timepoints, binary outcomes in a prospective cohort design: study sample size requirements

Summary of Calculations, based on references 1-3:

RR	risk ratio	0.75
Pa	proportion with diarrhea in exposed	0.12
Pb	proportion with diarrhea in unexposed	0.16
Qa	1-Pa	0.88
Qb	1-Pb	0.84
	Za/2	1.96
	Zb	0.8416
P bar	(Pa+Pb)/2	0.14
Q bar	1-Pbar	0.86
n	number of postbaseline obs per pers	4
rho	intraclass corr coeff (ICC)	0.05
d	smallest diff to be detected	0.04
m	number of participants per group	339.2757
h	households needed at 5.8 ppl/house	58.4958
For clustering within households, we must use another ICC (3)		
ICC	intracluster correlation coeff (rho)	0.05
m	number of subjects in a cluster (hh size)	5.8
k	number of clusters	58.4958
DE	design effect	1.24
RSS	required # people = subjects * DE	420.7018
Adj HH	Total adjusted households needed	**72.5348**

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