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Improving Household Drinking Water Quality: Use of Biosand Filter in Cambodia

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Field Note

Improving Household Drinking Water Quality

Use of BioSand Filters in Cambodia

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Despite recontamination during storage, the concentration of *E. coli* as well as turbidity were still lower in BSF-treated and stored water than in untreated water.

Executive Summary

Safe water is critical to preventing diarrheal disease, which kills nearly two million children annually. A promising household water treatment technology is the BioSand Filter (BSF), an intermittent slow sand filter that is locally produced in Cambodia and several other developing countries. However, despite promising laboratory performance, the BSF lacks adequate description and epidemiological evidence on its field performance and health impact.

Cambodia is currently the country with the largest number of BSFs in the world. Although non-governmental organizations (NGOs) have conducted internal evaluations, no independent evaluations using scientific methods have measured the performance of these filters to improve water quality and reduce waterborne diarrheal disease in Cambodia. Moreover, the long-term use and effectiveness of BSFs have not been examined and these studies are necessary before further BSF implementation and scale-up projects can occur.

The purpose of this research was to assess: (1) the factors associated with continued BSF use or disuse by using a cross-sectional survey (2) the microbiological effectiveness of the BSFs still in use by measuring reduction of *Escherichia coli (E. coli)* bacteria, and (3) the health impact of the BSF as determined by a epidemiological study in which diarrheal disease incidence was measured among people in households with a BSF (intervention) versus people in similar households without a BSF (control).

Results of these studies indicate that 87.5% of the households surveyed had BSFs in use. Time in use ranged from six months to eight years, and the percentage of BSFs still in use did not decline over the length of time elapsed between BSF installation and follow up. Water, sanitation, hygiene, and other factors were analyzed for association with continued filter use. Households who reported receiving training in operation and maintenance and those who used deep wells (more than 10 meters deep) were found to be statistically significantly associated with continued BSF use. In BSF households, BSF treatment resulted in a 95% reduction of *E. coli* and an 82% reduction in turbidity of untreated source water. Furthermore, BSF-usage in households resulted in a 47% reduction of diarrheal disease as compared to control households that did not have BSFs. However, a significant proportion of BSF-treated and stored samples became re-contaminated after filtration suggesting the need for additional training and education about safe storage and recontamination. Despite recontamination during storage, the concentration of *E. coli* as well as turbidity were still lower in BSF-treated and stored water than in untreated water.

The BSF is a robust water treatment technology for use in rural Cambodian households, capable of effective removal of indicator bacteria, specifically E. coli, and significant reduction of diarrheal disease. BSF performance is comparable to other recommended household water treatment interventions, such as the ceramic water purifier; however BSFs provide the additional advantage of not being prone to breakage or needing replacement parts. Overall, the findings of this study provide evidence that the BSF is a promising household point-of-use (POU) water treatment option to achieve sustained access to safe water.

Bottled water is an expensive solution; treatment at home is more sustainable.

Study Background

Access to safe water is not only a basic requirement for life, but is also regarded as a human right. It is estimated that more than 1 billion people, nearly 20% of the world's total population, do not have access to safe drinking water[1]. Worldwide, 88% of diarrheal disease is due to unsafe water, hygiene, and sanitation[2]. Consuming unsafe water causes gastrointestinal illnesses that lead to diarrhea, dehydration, and malnutrition, especially for children in developing countries. Children are more vulnerable due to undeveloped digestive and immune systems and experience an average of three or more episodes of diarrheal disease each year[3]. Of the 1.7 million people that die each year from diarrheal disease, 90% are children under the age of five, mostly in developing countries[1].

The BioSand Filter (BSF) is an emerging Point-Of-Use (POU) water treatment technology that is currently being implemented and promoted internationally. Laboratory studies have examined BSF performance, including its ability to reduce different classes of microorganisms[4,5,6]. These studies show reductions ranging from 90% (1 log_{10}) to 99% (2 log_{10}), for fecal coliforms, including *E. coli*, approximately 90% (1 log_{10}) for viruses, and >99.9% (>3 log_{10}) for protozoan parasites. While these microbial reductions are encouraging, independent field examinations of the BSF to assess long-term changes in water quality, health impact, and sustainability are still lacking. The purpose of this study was to conduct an independent follow-up assessment of two large-scale NGO implementation programs of the BSF in Cambodia. The study was designed as a microbiological and epidemiological assessment of BSF impact on water quality and health after introduction into homes beginning in 2001. Key study questions were:

- How long are BSFs being used and what factors are related to continued BSF use?

- Are those BSFs still in use able to improve household drinking water quality by reducing E. coli levels in drinking water?

- Are those BSFs still in use making a significant impact on household health by reducing diarrheal disease?

Even sources classifed as "improved" may provide water that is microbiologically contaminated.

Another factor related to poor surface water quality is low quality or complete lack of sanitation facilities. Nearly 80% of the rural population reports not having a toilet facility and therefore making use of fields or bush areas. A lack of access to sanitation facilities has significant impact on human health as wastes are discharged into surface waters that are also used for drinking.

Box 1: Household Water Treatment in Cambodia

Access to safe water for Cambodians remains a problem throughout the country, especially for the rural population. More than 40% of Cambodians use unimproved drinking water sources during the dry season (November to April), with 23% of the population relying on surface waters such as rivers, lakes, ponds, and streams (see table 1). During the rainy season (May to October), when rainwater harvesting is more prominent, use of unimproved drinking water sources decreases to 24%. However, unimproved surface waters are still used by 11% of the total population during this time[7]. Furthermore, even sources classified as "improved" may provide water that is microbiologically contaminated. In addition, exposure to hazardous chemicals in drinking water is a serious issue in the Mekong region because some groundwater sources are also known to contain high levels of naturally occurring arsenic and other chemical contaminants[8,9,10]. Surface and shallow ground waters that are of poor microbiological quality are often used as alternatives to arsenic-contaminated deep wells[11]. The fact that nearly 80% of the rural population do not have a toilet and practice open defecation[7] also impacts water quality and health as wastes contaminate surface waters that are used for drinking.

Water treatment is widely practised at the household level, with boiling the most commonly used method (60% of the total population). Other methods are also used and over 2% of the population uses household filtration (ceramic, sand, or other filter)[7], which translates into approximately 55,000 households who make use of this treatment method. Production and promotion of household water treatment technologies have been going on for many years, and Cambodia now serves as an important place for household water treatment research, demonstration, and implementation[11].

Research has shown that POU drinking water treatment is both a technically- and financially effective intervention for provision of safe water to consumers[12]. Recent systematic reviews of various research studies show that POU technologies can improve water quality and reduce diarrheal disease by 30% to 70%[13,14,15]. Diarrhoeal disease reduction varies widely however, based on a variety of factors[16]. Besides being evaluated for the ability to reduce pathogens and disease, 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.

Table 1: Unimproved water sources in rural and urban Cambodia during the dry and rainy seasons (NIPH/NIS 2006)

Dry Season	**Urban**	**Rural**	**Total**
All unimproved water sources	25%	46%	43%
Surface waters	12%	25%	23%
Rainy Season	**Urban**	**Rural**	**Total**
All unimproved water sources	12%	26%	24%
Surface waters	5%	11%	11%

Box 2: The BioSand Filter

The BioSand Filter (BSF) is a household-scale, intermittently-operated slow sand filter invented in its current form by Dr. David Manz in the early 1990s. An estimated 320,000 BSFs have been installed throughout the world in more than 70 counties[17]. Unlike a traditional slow sand filter, the BSF is specifically adapted for use in the home because it is relatively small and does not require constant delivery of untreated water. The BSF is a robust technology with no moving parts and can be constructed using locally available materials.

Figure 1: BSF cross-section

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 gravel. The BSF is operated intermittently by pouring untreated water into the top, which then flows down the length of the filter bed by gravity. Filtered water exits the BSF from a bottom outlet pipe (usually PVC plastic) that is directed upwards as a standpipe. Filtered water then flows from the standpipe into a bucket, bottle, or, ideally, a safe storage container, which is not included with the BSF, but makes usage much easier. Typical BSF flow rate is 0.75 liters per minute, which makes it possible to obtain up to 45 liters of water in an hour[18].

There are four mechanisms within the BSF responsible for the removal of impurities. First, the BSF standpipe exit is at a level that allows for a standing layer of water to remain above the sand surface at all times, including the periods between intermittent addition of untreated water to the top of the BSF. The maintenance of shallow water above the sand bed allows a complex biological layer (or "schmutzdecke") to establish and remain on the surface of the sand. This metabolically active microbial community contributes to the filtration mechanisms that trap and/or naturally decompose disease-causing microorganisms and other dissolved impurities and particles in the untreated water. A recent study has shown that microbial reductions improve as this biological layer matures (or "ripens") and when less than one pore volume of water (the volume of water that the BSF is capable of holding) is filtered per day[6]. A rectangular plate with small holes (diffuser plate), located several centimeters above the sand bed and standing water, prevents disruption of the biological surface layer when untreated water is added to the BSF.

Second, as the water continues to flow down the sand column, organisms become trapped in fine sand and may stick to sand grains due to a static charge (adsorption).

Third, as sand deep within the filter bed acquires a coating over time (referred to as "aged sand"), it becomes more effective at absorbing microorganisms and other particles[19]. Finally and fourth, as water continues farther down the sand column, lack of light and nutrients causes microbes to naturally die off.

Success depends on a participatory and integrated approach involving health, hygiene, and sanitation education and promotion, training in BSF operation and maintenance, and continued monitoring of practices.

Box 3: BSF Implementation in Cambodia

In 1997, Samaritan's Purse Canada (SPC), an international relief organization, first introduced the BSF into Cambodia through technology workshops. SPC focuses on the BioSand Filter as a main component in improving health and quality of life, but also recognizes that success depends on a participatory and integrated approach involving health, hygiene, and sanitation education and promotion, training in BSF operation and maintenance, and continued monitoring of practices. The household water program employs a partial subsidization model, involving both financial participation and sweat equity, from individuals and communities.

The program engages local partners, including the NGOs Hagar Cambodia and Cambodia Global Action (CGA; formerly Assemblies of God), in BSF implementation into Cambodian communities. Hagar Cambodia began BSF implementation in 1999, and later trained CGA in the BSF technology. Both organizations target beneficiaries who are considered poor, living in rural communities, and are dependent mostly on contaminated surface and well water for drinking purposes. Hagar Cambodia and CGA work closely with SPC, receiving financial, technical, and managerial support. While some parts of their implementation programs are similar, there are differences as well. Globally, SPC and local partners have implemented more than 100,000 BSFs in the last 12 years and currently implement over 25,000 BSFs per annum.

Hagar Cambodia BSF Program

At the time of this study (2005-2007), the Hagar Cambodia BSF program operated in three provinces: Kampong Thom, Svay Rieng, and Kratie. Each province was covered by a construction / community health education team and in addition a mobile team moved to other provinces across the country to implement BSF projects and program activities. Commune leaders from rural communities in the provinces submitted written requests to apply for BSF projects for their community. Community meetings were then held by the Hagar Cambodia team to introduce and promote the BSF to villagers and to invite households to participate in health education meetings and training on the BSF. Priority was given to poor and single parent homes.

Interested households, who were able to contribute financially, paid 8000 Riel (approximately US$2) to participate in the BSF program. BSFs were constructed in batches of 10, with a member from each of the 10 participating households involved in construction of their BSF. Construction occurred in the morning hours under instruction and supervision from the construction managers. In the afternoon, participating family members prepared filter media by washing pre-sifted sand and gravel extracted from Charam Mountains in the Kompong Speu Province of Cambodia. Each family was required to collect and transport their BSF to their home two days after construction, with the wait allowing for curing of the filter. Each BSF was installed by one of the Hagar Cambodia teams with assistance from an individual in the household. A household caretaker was charged with maintaining the BSF on a daily basis, typically the mother or the elder daughter. Money from the participating households was placed in a fund that was used for the construction of latrines or wells for the community.

In addition, each household was required to attend a BSF training session and a health education meeting hosted by Hagar Cambodia staff. Households received a printed brochure with pictures portraying BSF use and maintenance. The Hagar team returned one and three months following installation to monitor BSF use and to answer any questions the households may have had. A third follow-up visit was conducted between 6–12 months after the first follow-up visit. The Hagar Cambodia concrete

BSF program has installed the largest number of BSFs in Cambodia (more than 25,000 at the time of this study; approximately 45,000 presently) by an NGO.

CGA BSF Program

To target and survey communities that would benefit from the BSF program, CGA used Participatory Rural Appraisal, an approach in which the rural community aids in the planning and management of development projects. Suitability was not only based on need for safe water access, but was also determined by other factors, including support from community leaders, agricultural activities and practices, community water sources, socio-economic status of households in the community, and willing volunteers to form committees.

Having to carry water home over a long distance limits the amount used.

A Program Unit (PU) composed of a coordinator, three trainers, the Provincial Department of Rural Development (PDRD), and the participating villagers elected Village Development Committees (VDCs) who were trained to manage and coordinate the BSF project. The VDC recruited volunteers from the community and trained them about health and hygiene, sanitation, and water. Interested households attended weekly meetings about the BSF program prior to receiving a BSF. VDCs were active in the community for two months prior to the start of BSF installations. BSF beneficiaries were expected to contribute 8000 to 12,000 Riel (US$2–$3) for a filter.

Three villagers were recruited to form a Program Management Committee (PMC) to help manage the BSF program in the community by monitoring installations, troubleshooting problems with the BSF, and conducting follow up. The PMC was responsible for purchasing materials for construction, washing the filter media, assisting with the construction, finding water for installation, and conducting follow-up two months post-installation. Households were required to contribute two hours of construction labor as well as arrange for transport of the BSF to their house. Each household was also given instructions on BSF use and maintenance. Money collected by the PMCs was applied to training materials and activities. PMC members were paid a small amount to install the BSFs (2000–3000 Riel or US$0.50–$0.75 per filter).

The study had two main objectives: To find out about continued use of the BSF as well as factors influencing use or disuse, and to determine the impact of the filter on water quality and diarrhoea.

Table 2: Comparison of BSF implementation programs in Cambodia at the time of the study

	HAGAR CAMBODIA	CGA
Implementation Strategy	Community-based, NGO-subsidized intervention projects; sales to NGOs	Community-based, NGO-subsidized intervention projects
Focus	Community-based, provincial construction and health teams	Participatory Rural Appraisals, Volunteer Development Committee (VDC), and Program Management Committees (PMC)
Beneficiary Contribution	Financial, labor (sand washing, construction), transportation, attend health and hygiene training.	
Manufacturing Model	Manufactured by participating households, supervised by program staff	Constructed by CGA staff, participating households, and the VDC
Media	Media sand is crushed rock pre-sifted using 1 mm mesh	
Quality Control Measures	Follow up at 1 month, 3 months, 6-12 months after filter installation	Follow up at 1 and 2 months, and ongoing at the request of the household
Unit Production Cost[a]	US$15.50[b], including plastic storage container for treated water	
Replacement Parts Cost	There are no replacement parts; US$2.50 for a new water storage container	
Participation Cost to Users	US$2[c]	US$1-$3, depending on local costs of materials[c]
Training	BSF training in community groups and at the household level during installation; community health group training sessions hosted by health trainer (staff)	BSF training at the household level; community health education training
Total Filters Built to Date (June 2009)	45,000	8,000

[a] Not including labor, transportation, education materials, etc.
[b] As of 2009 unit production cost is approximately US$19 including water storage container
[c] As of 2009, participation cost to users is US$4

Study Design And Materials

The current study was carried out to address the two key questions:

1. An initial cross-sectional survey of households previously provided with BSFs to determine continued use and factors that influenced use or disuse.
2. A epidemiological study of a selection of the cross-sectional households still using the BSF (intervention) and similar households not using a BSF (controls) to determine the impact of the BSF on water quality and diarrheal disease.

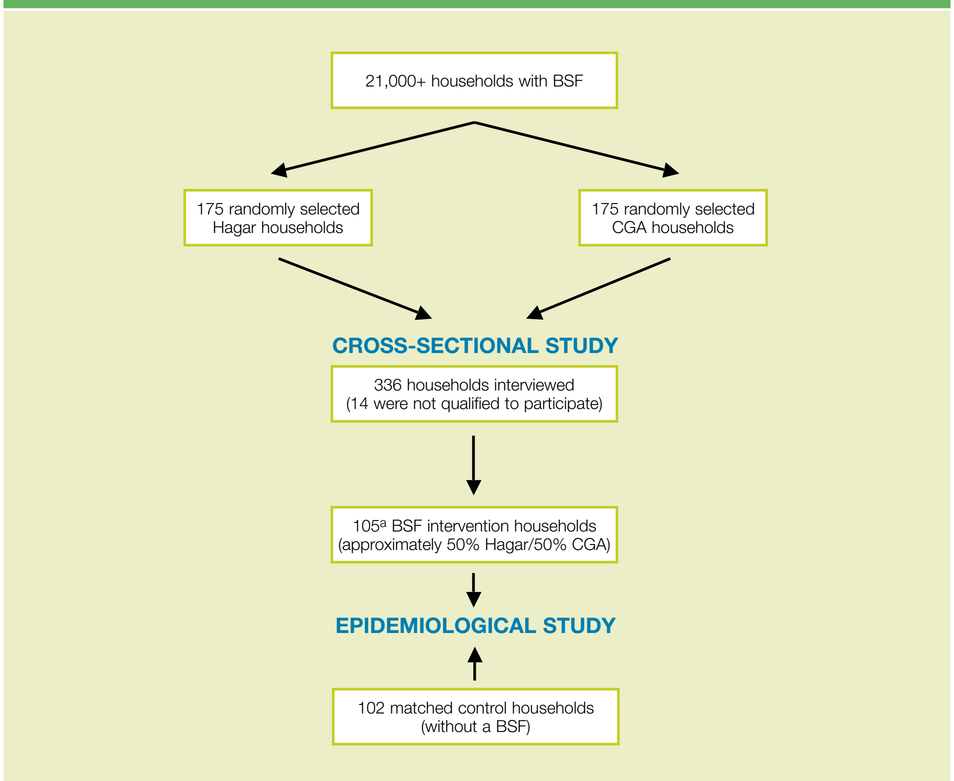
Cross-Sectional Study Design and Methods

To determine continued use and factors that influenced use or disuse of the BSF, a master list of all households from both Hagar Cambodia and CGA programs was compiled. The study population consisted of households in communities that had at least 20 BSFs. The BSF projects by Hagar Cambodia were located in 11 provinces throughout Cambodia, where they introduced approximately 19,600 BSFs between 2001 and 2006. However, the majority of their BSFs were installed in three provinces: Kampong Thom, Kratie, and Svey Rieng. Between 2002 and 2006, CGA introduced 2,668 BSFs largely in two provinces: Kandal and Kampong Speu. These were the five provinces included in the present study (Figure 3).

As depicted in Figure 2, a random selection of 175 BSF households from both Hagar Cambodia and CGA master lists were chosen for the cross-sectional study. Both organizations keep records of BSF recipient households for follow-up and quality control programs. While the information gathered on BSF communities and households by each organization differs, their records were considered adequately representative and complete for the purposes of this study.

Inclusion criteria for participating households in the cross-sectional study were: (1) the household had received a BSF from the implementing organization, (2) the family or household was living in the original location where they had received the BSF, and (3) willingness to participate in the study. A field staff team was composed of one study coordinator and six local staff. A trained field staff member approached eligible households for agreement to participate in the cross-sectional study. The cross-sectional study examined the continued use of BSFs in households that were part of large-scale BSF implementation programs. Data were collected from cross-sectional households for a number of key variables, including BSF

Figure 2: Overview of the study approach of the BSF in Cambodia



a Two additional households quit prior to the completion of the study

All participating households were required to have at least one child under the age of five years living in the household, as differences in diarrheal disease rates in this age group were the main outcome of interest in the longitudinal study.

operation and maintenance, water source and sanitation. These variables were analyzed for association with BSF use and are described in detail below. Other technical, behavioral and economic factors possibly influencing the decision of BSF use or disuse may also deserve further consideration, but were beyond the scope of this study. Using analysis of "yes/no" outcomes to questions (also called bivariate analysis), unadjusted odds ratios (OR) were generated for each factor and were considered statistically significantly associated with continued BSF use if the OR was >1 and the 95% confidence interval (CI) did not contain any values smaller than 1.0. Likewise, a factor was considered statistically significantly associated with BSF disuse if the OR was <1 and the 95% CI did not contain any values larger than 1.0 (see glossary for further explanation of terminology).

BSFs were considered "in use" if:

1. The BSF was in working order. Visual inspection of the top layer of the sand, measurement of the biofilm depth, examination of the diffuser plate placement, examination of the area surrounding the filter outlet, measurement of flow rate, and other indicators consistent with filter use were performed to determine if all filter parts were intact and functional; and
2. Households reported that the BSF was used at least once within the previous week.

The study also examined filter use practices and user acceptance and collected information on household demographics, socio-economic status, water-handling practice, sanitation and hygiene practices, and other health-related behaviors. Data were collected from the months of November 2006 to January 2007 and were analyzed to determine factors associated with long-term BSF use by utilizing unadjusted odds ratios.

Epidemiological Study Design and Methods

The type of study used to determine health impact is properly called a "Longitudinal Prospective Cohort Study" (see also the glossary). To determine the impact of the BSF on water quality (*E. coli* reduction) and diarrheal disease in user (intervention) households as compared to non-user (control) households, households initially recruited for the cross-sectional survey were randomly selected for the longitudinal study. Fifty-three households were randomly

Figure 3: Map of Cambodian provinces included in the study

[This map is for illustrative purposes and does not imply the expression of any opinion on the part of the authors or publishers of this report concerning the legal status of any country or territory or concerning the delimitation of frontiers or boundaries.]

Washing the media prior to filling the filter.

selected from the cross-sectional list from Hagar Cambodia project sites in Kampong Thom, Kratie, and Svey Rieng Provinces and 51 households were randomly selected from CGA project sites in Kandal and Kampong Speu Provinces. Each intervention household recruited for the longitudinal prospective cohort study was then matched with a control household located within 1 kilometer from the intervention household. All participating households were required to have at least one child under the age of five years living in the household, as differences in diarrheal disease rates in this age group were the main outcome of interest in the longitudinal study.

A trained field staff member approached eligible households for consent to participate in the longitudinal study. To account for changes over time in both water quality and community diarrheal disease burdens, field staff visited each household five times (approximately once per month) between January 2007 and May 2007. Longitudinal interviews were intended to capture information on diarrheal disease for each family member based on a 7-day recall period by the respondent as well as water and hygiene practices, education, and sanitation.

Household drinking water samples were also collected from intervention and control households. Three types of household drinking water samples from each BSF household were collected during each visit: drinking water source prior to treatment, BSF-treated water (effluent), and stored BSF-treated water. Two types of water samples from each control household were collected during each visit: drinking water source and stored drinking water (occasionally treated by another method). Laboratory analyses of water samples were conducted in the environmental microbiology laboratory at Resource Development International Cambodia (RDIC) in Kien Svay (Kandal Province). Membrane filtration was used according to standard methods, with substitutions for biological media, to assay for total coliform and *E. coli* concentrations (colony forming units per 100 ml). Turbidity (NTU; see glossary) was measured by a Hach® turbidimeter.
All participating households in the study were provided with a household water and hygiene kit that included a 20-liter 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 longitudinal study. The water kits were provided at no cost to the household and distributed by the field team in July 2007, after the fifth household visit.

More than 300 households were interviewed by trained field staff.

Results of this study indicate continued BSF use, in one case up to eight years, as well as significant water quality improvements and a substantial reduction in diarrheal disease.

BSF Sustainability

Ultimately, sustainability of POU technologies can be demonstrated if usage becomes part of the daily routine of every household member. Recent publications addressing sustainability have identified the BSF as having the potential to achieve sustained and consistent use, as it involves a one-time purchase, requires little time and effort to use, produces sufficient water for daily use, and improves appearance and often the taste of water[21,22]. Results of this study indicate continued BSF use, in one case up to eight years, as well as significant water quality improvements and a substantial reduction in diarrheal disease. Additional work examining the sustainability and disease reduction of the BSF in Cambodia should consider how eliminating subsidies may influence these findings. Based on the results here and in other work, future studies in Cambodia should evaluate additional factors related to sustainability of BSF and other technologies such as: seasonal changes in water usage, use of arsenic-contaminated water, technical alterations to the BSF that improve production and distribution, specific implementation models, and possibly other social, behavioral, and economic influences. While opinions regarding scale-up of POU technologies differ, there is general agreement that longer-term studies (such as this one) are required to provide better evidence of continued behavior change, sustained product performance, and health impact.

Results For Cross-Sectional Assesment Of Contimued Use Of BSF

Out of the 350 randomly selected households from Hagar Cambodia and CGA master lists, a total of 336 households (96%) completed the cross-sectional survey conducted from November 2006 to January 2007. Fourteen of the randomly selected households did not meet inclusion criteria and were not included in the study. Of those participating, 40% of households were located in Kandal Province, 9% in Kampong Speu Province, 16% in Svay Rieng Province, 18% in Kampong Thom Province, and 17% in Kratie Province. More households were selected from Kandal Province because it was where the majority of CGA BSFs had previously been installed. Overall, 1986 people participated in the study, with an average household size of 5.9 people. Females made up 51% of the participants.

Select Water, Sanitation, and Hygiene Findings

In the survey, 47% of households reported traveling less than 10 meters and 45% traveled between 10 and 100 meters from home to the water source. These percentages closely resemble findings in the 2005 Cambodia Demographic and Health Survey (CDHS)[7], which reports that 42% of Cambodians have a drinking water source on the household premises while 40% travel less than 30 minutes roundtrip to retrieve drinking water.

According to the CDHS, 60% of Cambodians boil water prior to drinking while 2% use some form of filtration. More than 30% do not treat drinking water. In the present study, nearly all study households reported using some form of water treatment. When questioned about the uses for treated water, 99% of respondents reported for the purpose of drinking, 67% for washing or preparing food, 30% for washing dishes and kitchen equipment, 10% for washing hands, and 7% for bathing water. The majority (91%) of families reported that their chosen treatment method always provided enough drinking water for the family.

Of the 336 study households, nearly all (99%) reported using a container to store water. The majority of storage containers for treated water (66%) were made of plastic, while traditional ceramic or concrete jars were reported by 11% of the study population. The vast majority of respondents (93%) reported cleaning their water storage containers, while only one-half of respondents reported covering their storage containers. Only 21% of households reported using a safe method

Families play a role in producing their own filter, here filling the mould with concrete.

(tap or pouring) to draw drinking water from the water storage container.

When questioned about BSF accessibility for purchase either independently or through implementing organizations, the majority of households (74%) reported that they could not be purchased in the area, while 15% of respondents did not know. If the BSF was broken or had problems, the majority of the respondents (65%) said they would seek help from the implementing organization (CGA or Hagar Cambodia), indicating that households recognize the implementing organization as the main resource for technical assistance with filter problems.

The 2005 CDHS also reports that only 22% of Cambodians have access to improved sanitation. However, the majority of households in the cross-sectional study (60%) had access to sanitation facilities, while the remaining reported using grounds, fields, or plastic bags as places for defecation. No households were connected to a conventional sewerage system. The vast majority of households (96%) had soap on the premises. Eighty-one percent of cross sectional households reported that the household members washed their hands with soap. Thirty households (9%) reported using other materials, such as sand, to clean hands. Respondents reported practicing hand-washing after defecation (70%), before preparing food (56%), after eating (83%), and after performing household or caretaking activities (23%).

Filling the Biosand Filter

When households were asked about the cause(s) of diarrhea in children, contaminated water was reported most often (70%), followed by food (66%), poor hygiene (66%), and other causes (23%). According to 90% of household respondents, diarrhea can be prevented. The leading diarrhea prevention measures reported were boiling water (78%), properly preparing food (75%), and cleaning hands (43%).

BSF Use and Disuse

Of the 336 households in the cross-sectional study, BSFs were considered “in use” in 294 (87.5%) of households at the time of the visit. Households reported using an average of 46 liters of water from the BSF per day, with an average of 13.6 liters per day being used specifically for drinking. Households still using the BSF had been using them from six months (n=84) up to eight years (n=1). As shown in Figure 4, the percentage of filters still in use (of total households interviewed) did not decline over time. The proportion of BSFs in use is not strongly associated with the length of time elapsed between BSF installation in the household and follow up. When analyzed statistically, there was not a strong

Three factors were statistically significantly associated with BSF disuse: inadequacy of filtered water quantity, boiling water as an alternative treatment method, or consuming water directly from the untreated water container or from the source.

association between time in use and BSF use (the OR = 0.99 but lowest CI value is <1.0)).

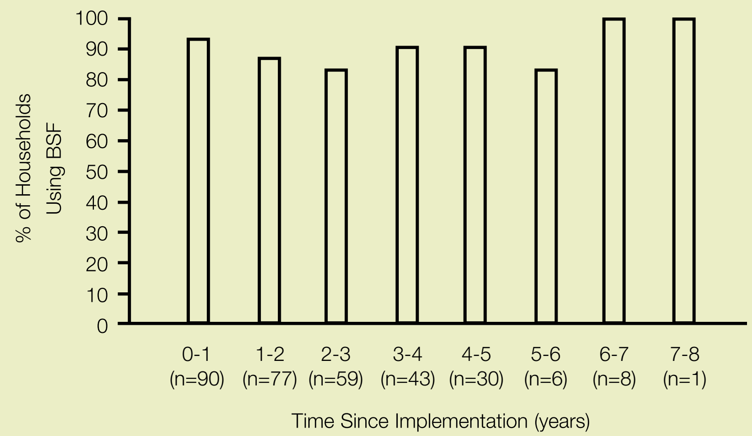
While 12.5% of households were no longer using a BSF, all non-user respondents reported having used the BSF at some point. Of those no longer using the BSF, one-half provided a reason: 13 households (62%) cited the dissatisfaction with color, taste, or smell of the BSF-treated water; six households (29%) reported they were unable to fix a problem they encountered or felt that the BSF did not work as they had expected; and two households (10%) reported that they gave the BSF away. Eighty-three percent of households no longer using the BSF reported that they used at least one other form of water treatment; the majority of these households reported settling as their primary treatment method.

Data were collected from cross-sectional households for a number of key variables, including BSF operation and maintenance, water source, sanitation, and wealth index. These variables are analyzed for association with BSF use and are described in detail below. Other technical, behavioral and economic factors possibly influencing the decision of BSF use or disuse may also deserve further consideration, but were beyond the scope of this study.

BSF Operation and Maintenance

Several factors related to BSF operation and maintenance practices were analyzed for association with continued BSF use. Of these, two factors related to operation and maintenance and one factor related to

Figure 4: Percent of households (of total households interviewed, or n) using the BSF at follow-up as a function of time (years) since implementation, across all provinces



water source were found to have a statistically significant association with continued BSF use (Table 3).

- 63% of households using the BSF reported that they had received **training in operation and maintenance of the BSF**. While all households included in the cross sectional study were at one time provided with BSF training or instruction, these data suggest that 37% of cross sectional households do not recall receiving this information. Households who reported having received training were two times as likely to be using their BSF at the time of the survey as compared to households who reported they had not received training.
- The **method for dispensing water** from the household storage container was also found to be strongly associated with continued BSF use. Households that reported use of a dipper to dispense water were three times as likely to be using their BSF at the time of survey compared to households that poured directly from the container or used a tap.

Three factors were statistically significantly associated with BSF disuse: inadequacy of filtered water quantity, boiling water as an alternative treatment method, or consuming water directly from the untreated water container or from the source. All other BSF operation and maintenance variables tested, including number of times the BSF was used per day, type of storage container, practices of covering storage container, cleaning the storage container or filter spout, checking flow rate, how to resume flow rate, or whether the household had experienced a problem with the filter, were not found to be strongly associated with either continued use or disuse of the BSF.

Table 3: Factors statistically significant associated with continued BSF use

Factor	BSF Users n = 294	Non-users n = 42	Unadjusted OR (95% CI[a])
User reported receiving training on operation and maintenance of the BSF[b]			
Yes	184	19	2.04
No	109	23	(1.01 – 4.16)
Method of drawing water for drinking (observed by interviewer)			
Dipper or instrument	241	25	3.09
Pour/Tap	53	17	(1.56 – 6.13)
Use of deep well[c] as drinking water source			
Deep well	142	11	2.63
All other sources	152	31	(1.27 – 5.40)

[a] 95% confidence interval
[b] Data missing from one BSF user household
[c] Deep well was defined as a well with a depth greater than 10 meters

Water Source

Cross-sectional study participants reported water source(s) that they used during the rainy season (Table 4). When considering all water sources used, rainwater was the most widely used water source for both BSF households (67%) and non-BSF households (64%), followed by deep wells (48% and 26%, respectively), and then surface waters (38% and 52%, respectively).

Water sources that the study households used in the rainy season were examined in relationship to continued BSF use. Water source types were grouped according to three main source categories: vulnerable water (surface waters including lakes, ponds, rivers, streams, channels, and shallow wells), protected ground water (wells deeper than 10 meters), and rainwater. For each main water source category, households were classified by whether they had or had not used a source in that category during the rainy season. Of the water source data analyzed, use of deep wells was the only factor found to have a statistically significant association with continued BSF use. Households using deep wells as a drinking water source were 2.6 times as likely to be using the BSF at the time of survey compared to households using other sources of drinking water (also shown in Table 3)

Sanitation & Hygiene

Nearly 60% of BSF households and 67% of non-BSF households reported having access to sanitation; however no statistically significant association between continued use or disuse of the BSF and access to sanitation was found. Soap was observed in the vast majority of BSF and non-BSF households (97% and 93%

Access to improved sanitation was 56% for BSF households and 39% for control households, which is higher than the national average of 22% reported in the CDHS.

Table 4: Drinking water sources[a] during the rainy season reported by cross-sectional participants (number of households reporting and percent of all reported[b])

Source	No. (%[c]) Using BSF	No. (%[c]) Not Using BSF
Rainwater	196 (67%)	27 (64%)
Deep well (>10 meters)	142 (48%)	11 (26%)
River, stream, or channel	51 (17%)	11 (26%)
Shallow well	40 (14%)	8 (19%)
Lake or pond	21 (7%)	3 (7%)
Tap inside	3 (1%)	6 (14%)
Tap outside	3 (1%)	0 (0%)
Purchased and Other	11 (4%)	0 (0%)

[a] Households could report use of more than one source

[b] Percentage based on total households in BSF-usage category (BSF user = 294; BSF non-users = 42)

[c] Values may not add up to 100% due to rounding

respectively; the presence of soap demonstrated a positive, but not statistically significant association with continued BSF use. No significant association between washing hands with soap and continued BSF use or between the belief that diarrhea can be prevented and continued BSF use was found.

Results For Longitudinal Study

Study Participants and Households

A total of 209 households from the cross-sectional study were recruited to take part in the longitudinal study. The intervention group originally consisted of 107 households using BSFs and the control group consisted of 102 matched households that had never had BSFs. Only two households were lost to follow up in the intervention group, resulting in a final total of 105 intervention households (Figure 2). Of the households surveyed, there were a total of 1365 individuals; 53% were female and 19% were children under the age of five years. Other demographic factors of the longitudinal study households are presented in Table 5.

Box 4: Sanitation Access in Study Households

It is noteworthy that sanitation access and the hygiene proxies of soap presence and reported hand washing with soap in the study households were generally high. Access to improved sanitation was 56% for BSF households and 39% for control households, which is higher than the national average of 22% reported in the CDHS. The reasons for this greater access to sanitation and hygiene are uncertain, but could be related to the promotion of water, sanitation, and hygiene by the two BSF implementing organizations, Hagar Cambodia and CGA. Furthermore, sanitation coverage in Cambodia varies greatly with household income level, by village, by commune, and by province, so it was not unexpected to find such differences from the national average and among provinces in this study[23,24]. Important to the results of this study on BSF impact are the findings that rates for sanitation access, presence of soap, and hand-washing with soap were not significantly different between BSF and control households.

Table 5: Demographic characteristics of longitudinal study households, by intervention status[a]		
Characteristic	**BSF group**	**Control group**
Total participants	722 (53%)	643 (47%)
Number of females	373 (52%)	356 (55%)
Number of participants < 5 years of age	134 (19%)	135 (21%)
Total households	105	102
Average household size	6.8	6.3
Province (by household)	N = 105	N = 102
Kandal	39 (37%)	36 (35%)
Kampong Speu	13 (12%)	13 (13%)
Svay Rieng	17 (16%)	17 (17%)
Kampong Thom	20 (19%)	20 (20%)
Kratie	16 (15%)	16 (16%)
Formal education (by participants)	N = 722	N=634
Has not attended school	171 (24%)	189 (29%)
Primary school	313 (43%)	295 (46%)
High school	225 (31%)	158 (25%)
University	10 (1%)	1 (<1%)
Training Courses	3 (<1%)	0 (0%)
Reported receiving health education (by household)[b]	N = 105	N = 102
Yes	104 (99%)	79 (77%)
No	0 (0%)	23 (23%)
Missing data	1 (1%)	
Drinking water source in dry season (by household)[d,e]	N = 105	N = 102
Surface water	48 (46%)	51 (50%)
Deep well	48 (46%)	44 (43%)
Rainwater	4 (4%)	2 (2%)
Other	5 (5%)	5 (5%)
Treatment method used (by household)[e]	N = 105	N = 102
BSF	105 (100%)	0 (0%)
Boil	71 (68%)	34 (33%)
Settle	1 (1%)	46 (45%)
Chlorine	1 (1%)	22 (22%)
Other filtration method	0 (0%)	14 (14%)
Cover water storage (by household)	N = 105	N = 102
Yes	55 (52%)	48 (47%)
No	50 (48%)	54 (53%)
Observed method of drawing water (by household)	N = 105	N = 102
Tap / pour	18 (17%)	28 (27%)
Dipper / cup / other instrument	87 (83%)	54 (53%)
Missing data/no response		20 (20%)
Access to sanitation (by household)[c]	N = 105	N = 102
Yes	59 (56%)	40 (39%)
No	46 (44%)	62 (61%)
Soap observed in house (by household)	N = 105 100 (95%)	N = 102 96 (94%)
Wash hands with soap (by household)	N = 105	N = 102
Yes	82 (78%)	53 (52%)
No	12 (11%)	49 (48%)
Missing data/other	11 (11%)	

[a] Percentages may not equal 100% due to rounding or due to reports of multiple answers

[b] Health education was reported by participants from different sources including: radio, posters, school, health clinic or hospitals, village committee member, family member, NGO's, local pharmacy, etc. Topics related to health education included water management and use, sanitation and hygiene practices such as hand-washing, HIV/AIDS, food preparation, etc.

[c] Access to sanitation was defined has having access to a private or a shared toilet or latrine

[d] A well was considered deep if it had a depth of >10 meters. Shallow wells were included in the surface water group

[e] Not mutually exclusive

The majority of untreated water samples from both BSF and control households were in the high risk category.

Water Quality Analysis

In this phase of the study water quality analysis was done to determine both untreated and treated water quality in BSF and non-BSF households. The purpose of the analysis was to determine the extent to which BSF treatment improved the microbial quality of water. In both BSF and non-BSF households, treated water which was stored was also analyzed for quality. In the case of the BSF households the determination of water quality of BSF-treated water and BSF-treated and stored water made it possible to determine the extent to which BSF-treated water became re-contaminated after treatment and during storage and use. In addition, both untreated and treated water quality in BSF and control (non-BSF) households were compared to determine if they were similar or different. Microbial water quality was evaluated using *E. coli* as the fecal indicator microbe. The WHO categorizes drinking water quality into decimal risk levels according to concentrations of *E. coli* per 100 ml. Low risk is considered ≤10 CFU *E. coli* per 100 ml, intermediate risk is 11–100 CFU *E. coli* per 100 ml, and high risk as >100 CFU *E. coli* per 100 ml[25].

During each household visit over the five month longitudinal study, drinking water was collected from the household at the time of visit. Households with BSF contributed the following samples during this time: untreated water (before BSF treatment), BSF-treated water directly from the BSF and BSF-treated and stored water. Control households provided untreated water that was used for drinking as well as treated (by means other than the BSF) and stored water. The total number of samples vary per group depending on total number of households providing samples at the time of visit and the availability of different samples at the time of visit. In addition, BSF household sampling began in December 2005 during initial recruitment from the cross-sectional study whereas control household sampling began in January 2006.

Untreated Water

The majority of untreated water samples from both BSF and control households were in the high risk category, with 540 samples from BSF households (73%) and 364 samples from control households (82%)

Table 6: Number (percentage) of household drinking water samples in the longitudinal study by order-of-magnitude categories of *E. coli* concentration (CFU/100 ml)

	***E. coli* Concentration (CFU/100 ml)**				
	<1	**1 - 10**	**11 - 100**	**101 – 1000**	**>1000**
WHO Microbial Risk Category	**Low**		**Intermediate**	**High**	
BSF households					
Untreated n=737	3 (<1%)	111 (15%)	83 (11%)	**375 (51%)**	**165 (22%)**
Directly from BSF n=708	28 (4%)	**402 (57%)**	**184 (26%)**	72 (10%)	22 (3%)
BSF treated and stored n=589	10 (2%)	**157 (27%)**	**181 (31%)**	**154 (26%)**	87 (15%)
Control households					
Untreated n=445	0 (0%)	23 (5%)	58 (13%)	**247 (56%)**	**117 (26%)**
Treated and stored n=147	4 (3%)	**72 (49%)**	**39 (27%)**	24 (16%)	8 (5%)

[a] *E. coli* CFU (colony forming units) per 100 ml

[b] Treated by some means other than BSF including boiling, chlorination, or other treatment reported by households

categorized as having >100 *E. coli* per 100 ml (Table 6; Figure 5). The geometric mean *E. coli* concentrations in untreated water of BSF and control households were 170 and 355 *E. coli* per 100 ml, respectively. Average turbidities for water in BSF and control households also were high and above the WHO-recommended maximum of 5 NTU, at14.2 and 8.6 NTU, respectively. (Table 7). Untreated waters of BSF and non-BSF households had similar *E. coli* concentrations as can be seen in the plots in figure 6a.

Treated Water

Compared to untreated water, a much higher percentage of water samples were low or intermediate risk for *E. coli* after either BSF treatment (89% directly from the filter), after BSF treatment and storage (60%) and after treatment and storage in non-BSF households (79%) (Table 6 and Figure 5).

BSF-Treated Water

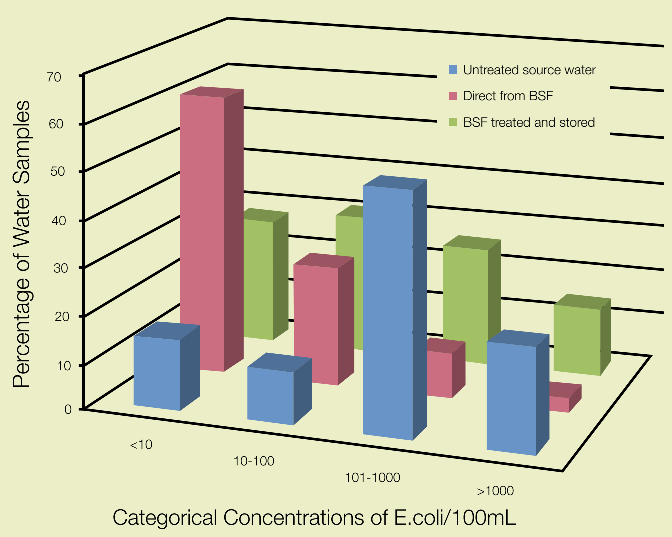
As shown in Tables 6 and 7, 61% of BSF-treated water samples collected directly from the BSF outlet pipe were in the WHO low risk category and only 13% of these samples were in the high-risk category (Table 6 and 7; Figure 5). Furthermore, as shown in Table 7, treated water samples taken directly from the BSF outlet of BSF households had a geometric mean of 8.1 CFU *E. coli* per 100 ml (WHO low risk category) and the arithmetic mean turbidity was 2.6 NTU. Overall, the average reduction of *E. coli* concentration following BSF-treatment was 95%. Turbidity of the BSF-treated water was reduced by an average 82%.

E. coli concentrations in untreated, BSF-treated and BSF-treated and stored waters from BSF households based on samples analyzed during the five month intervention period are summarized as box-and-whisker plots in Figure 6b. As seen in this figure, the middle 50% of readings of *E. coli* for untreated water (blue box on left) and BSF-treated water (red box in the middle) do not overlap, indicating significant improvements in quality and reduced concentrations of *E. coli* after treatment. Furthermore, statistical tests comparing untreated water and BSF-treated water confirm significantly different concentrations of *E. coli* between the two Overall, these reductions in concentrations of E. coli bacteria and turbidity (Table 7, Figure 6b) represent a significant improvement in water quality following BSF treatment.

BSF-Treated and Stored Water

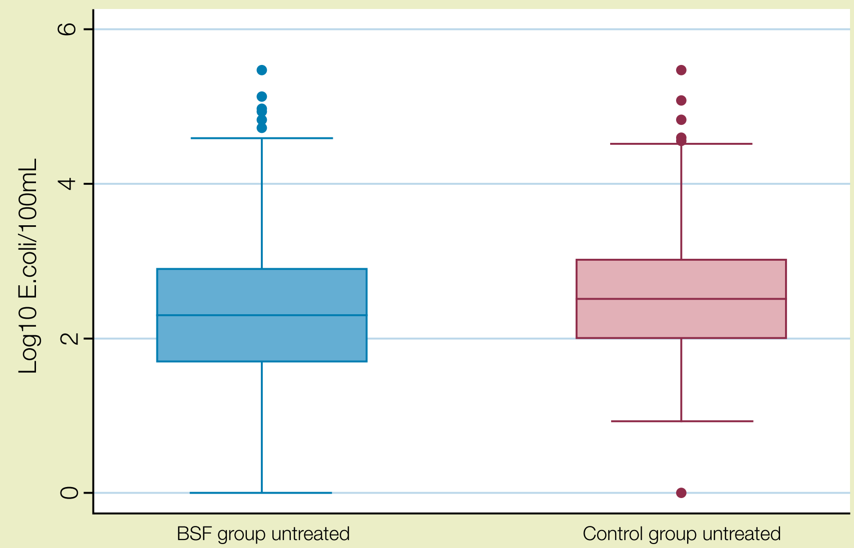
As shown in Table 6 and Figure 5 above, 29% of BSF-treated and stored water samples fell in the low risk category (≤ 10 *E. coli*/100ml), while 41% of these samples were in the high-risk category (≥ 100 *E. coli*/100ml). BSF-treated and stored water samples had a geometric mean *E. coli* concentration of 51 CFU *E. coli* per 100 ml (intermediate risk) and an arithmetic mean turbidity of 2.8 NTU. As shown in Table 7, BSF treated and stored water compared to untreated water has 69% lower average *E. coli* concentration and an 80% lower turbidity.

Figure 5: Percentage of BSF household untreated, BSF treated and BSF-treated + stored drinking water samples from the longitudinal study grouped by order-of-magnitude categories of E. coli concentration (CFU/100 ml).



Overall, the average reduction of *E. coli* concentration following BSF-treatment was 95%. Turbidity of the BSF-treated water was reduced by an average 82%.

Figure 6a; Log^{10} E. coli concentrations of untreated water samples from BSF (n = 737) and control households (n = 445), across five household visits.



The figure shows the median of the distribution of samples (line in box), the interquartile range (25%-75% of results, bottom and top of box) and the 95% confidence intervals (upper and lower lines) of the distribution of samples for untreated water. The dots show outliers.

As compared to water samples collected directly from the BSF outlet, water that was treated by the BSF and then stored had a higher percentage of high-risk samples (41%) and a decreased percentage of low-risk samples (29%) compared to BSF-treated water taken directly from the filter outlet (13% high risk and 61% low risk, respectively) (Table 6; Figure 5). *E. coli* concentrations in BSF-treated and stored water were on average 0.8 log10 higher than those of BSF-treated water collected directly from the outlet pipe. By statistical t-test, the E. coli concentrations of these groups were statistically significantly different ($p<0.0001$).

The use of cement jars for storage of rain water is very common in Cambodia.

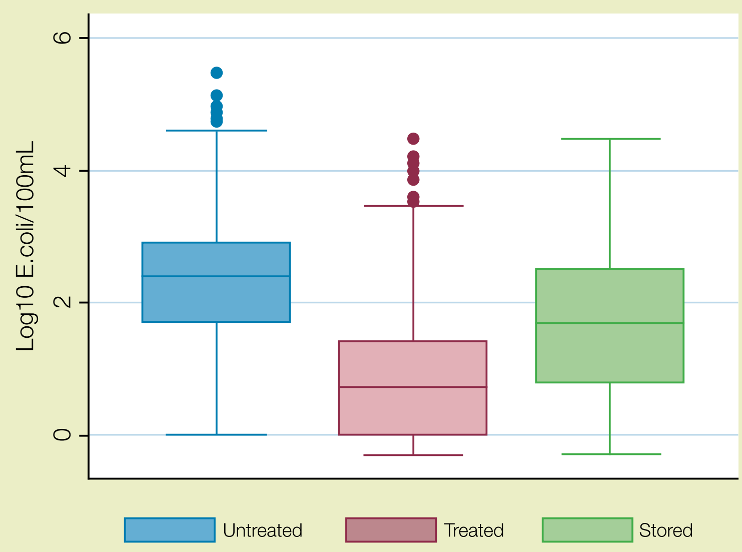
Table 7: Water quality data of intervention and control households and reductions following treatment and storage

	E. coli	E. coli LRV[a]	Turbidity	Turbidity
	CFU/100 ml, Geom. Mean and (SD)	(% Red.)	Mean NTU (SD)	(% Red.)[b]
BSF households				
Untreated n=737	170 (14)	---	14.2 (36.8)	---
Directly from BSF[c] n=708	8.1 (9)	1.3 (95%)	2.6 (11.7)	82%
BSF treated & stored n=589	51 (17)	0.5 (69%)[d]	2.8 (6.9)	80%
Control households				
Untreated n=445	355 (9)	---	8.6 (17.1)	---
Treated & stored n=147	12 (12)	1.2 (94%)	6.1 (10.2)	29%

NTU: Nephelometric units
CFU: colony forming units
SD: standard deviation
[a]Log_{10} reduction value of geometric mean
[b]Percent reduction of arithmetic mean
[c]Treated water collected directly from the BSF outlet pipe
[d]Reduction from untreated water

There was a slight (8%) but not statistically significant increase in turbidity of BSF-treated and stored water as compared to BSF-treated water collected directly from the BSF outlet. Overall, these results indicate that a significant proportion of BSF-treated water samples became re-contaminated during storage. However, despite recontamination during storage, the concentrations of E. coli as well as turbidity were still lower in BSF-treated and stored water than in untreated water, and represent a significant improvement in water quality.

Figure 6b: Log[10] concentrations of E. coli in the three types of water samples of BSF households across five household visits: untreated (n = 737), BSF treated (n = 708) and BSF treated and stored (n = 589).



The figure shows the median of the samples (line in box), the interquartile range (bottom and top of box) and the 95% confidence intervals of the distribution of samples.

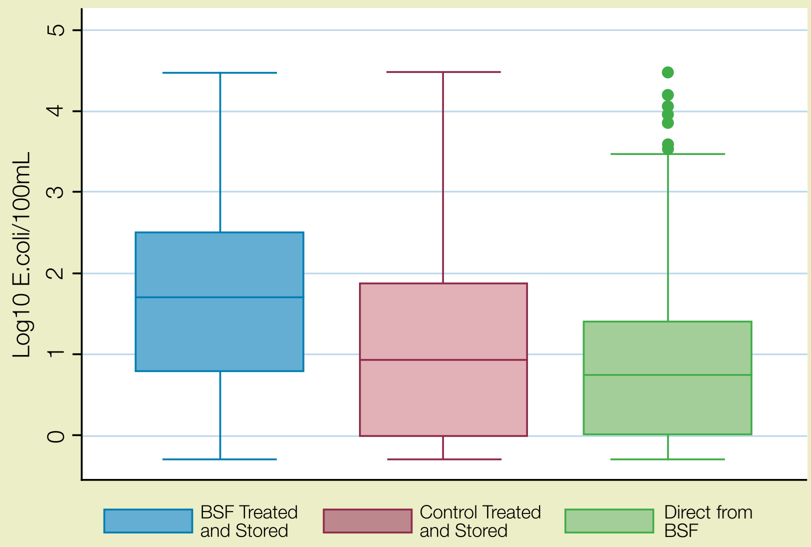
Treated and Stored Water of Control Households and of BSF Households

In control households where water was often treated by means other than BSF and then stored, this treated and stored water had a substantially lower percentage of water samples in the WHO high-risk category (21%) as compared to untreated water (82%) in these control households (Table 6; Figure 5). The treated and stored water samples of control households had a geometric mean E. coli concentration of 12 CFU per 100 ml (WHO intermediate risk level) and an arithmetic mean turbidity of 6.1 NTU that exceeded the WHO-recommended limit of 5 NTU (Table 7). It is noteworthy that the levels of *E. coli* in the treated and stored water of control

In the current study, a wide range of LRVs was found between untreated and BSF-treated or BSF-treated and stored water, including the occurrence of negative LRVs.

households at a geometric mean of 12 per 100 ml were lower than those of BSF-treated and stored water at a geometric mean of 51 CFU, although both are in the WHO intermediate risk category of 10-100 per 100 ml This difference in *E. coli* levels is also depicted in a box-and-whisker plot (Figure 6c) in which median E. coli concentrations and their interquartile ranges are visibly different, even though they overlap. The *E. coli* concentrations of these two groups were also statistically significantly different by an unpaired t-test (p<0.0001).

Figure (6c): Log_{10} E. coli concentrations of treateda and stored water samples from BSF and control households over five visits.



The figure shows the median (line in box), the interquartile range (bottom and top of box) and the 95% confidence intervals (upper and lower lines) of the samples of treated water direct from BSF (n=708) and BSF-treated and stored water (589) and treated and stored water from control households (n = 147). [a]Treatment in control households was by some means other than BSF including boiling, chlorination, or other treatment reported by households.

Pond water is a much preferred drinking water source that can be significantly improved through treatment.

A Note on Microbial Log_{10} Reduction Values

A microbial log_{10} reduction value (LRV) measures the extent of microbial reduction when untreated water is subjected to a microbial treatment process, such as the BSF. Brown et al.[11] have suggested that LRVs alone may be misleading. The LRV is a function of both the influent concentration and the effluent concentration of the microbes being tested. Therefore, low or non-detectable microbial concentrations in the influent sample may lead to an underestimate of the LRV, regardless of the true performance capability of the treatment process. Therefore, an uncensored or discrete LRV for one sampling event alone cannot accurately document the ability of the process to reduce microbes.

Before and after treatment.

In the current study, a wide range of LRVs was found between untreated and BSF-treated or BSF-treated and stored water, including the occurrence of negative LRVs. These situations, in which there was a higher microbial concentration in the BSF effluent water than in the corresponding influent water collected during an individual sampling event, may be due to a number of factors:

- The volume of water that passes through the BSF may not be sufficient to displace the entire volume of water inside the filter bed. Due to fluctuation in source water quality or changes in source water used, treated samples collected from the BSF may have originated from water with a different *E. coli* concentration than that of the untreated water sample taken on the day of the household visit. Therefore, sampling from the effluent water may not actually be indicative of the current quality of water being applied to the filter and may produce variable results.

- There may be a presence of high levels of *E. coli* in the biofilm (schmutzdecke) of the BSF from previously applied water having high *E. coli* levels. This could lead to the passage of some previously retained E. coli through the sand media and into the treated water.

- Some bacteria, such as *E. coli*, may grow in stored water and in storage vessels, which can result in underestimation of the ability of the BSF to reduce these bacteria. In order to reduce post-filtration fecal contamination, a container with a tap or a narrow opening that discourages other objects from being placed into the treated water is recommended . The extent to which E. coli growth that may have occurred in stored water or storage containers was not documented in this study.

- BSF components that come into contact with the BSF-treated water may be contaminated with *E. coli*. The water outlet spigot is the only part of the BSF outlet tube that is accessible to the user and it can be a source of contamination if exposed to *E. coli* from fecal contamination (such as on a person's finger) and is not properly cleaned. This is more likely in households where the BSF is easily accessible to animals, children, and other environmental contamination.

The rates of diarrhea for the intervention households were consistently lower than the rates for the control households over the course of the study,.

Summarizing risk reduction

Using the relative risk categories of WHO for decimal concentration ranges of *E. coli* to categorize drinking water quality, we can summarize filter performance by cross tabulating the risk category of water entering the filter against the risk category of water exiting the filter. Results of this cross-tabulation are shown below. The summary only applies to BSF users, and does not take into account changes in water quality due to storage. It is thus a simple summary of the performance of the filters alone. Of the 706 samples analyzed, the vast majority (514 or 73%) showed a relative risk reduction in categorical *E. coli* concentration (the sum of all filters in the light green boxes), only some showed no change in *E. coli* concentration risk category (136 or 19%; all filters in the dark green boxes), and very few (56 or 8%) were in a higher risk *E. coli* concentration category than they initially were (indicated by the grey boxes). Thus, BSF filtration generally improved the microbial quality of filtered water based on this comparison of risk categories.

	***E. coli* in Untreated Water (influent), as No./100 ml**				
Risk	**Low**	**Intermediate**	**High**		
E. coli in Treated Water (effluent), as No./100 ml	< 10	11-100	101-1000	>1000	Total
<10	75	51	215	87	428
11-100	24	20	95	45	184
101-1000	9	7	35	21	72
>1000	2	1	13	6	22
Total	110	79	358	159	706

Health Impact

Diarrheal Disease

Incidence rates of diarrheal disease were calculated by dividing the number of reported cases by the total number of person-time of observation. The cases of diarrhea per person-year for each group are presented in Figure 7. The rates of diarrhea for the intervention households were consistently lower than the rates for the control households over the course of the study, although each group experienced declining rates of diarrhea over the five-month observation period. The range of cases per person per year was between 4.4 and 6.3 for BSF households and between 8.0 and 9.9 for control households.

Statistical Analyses of Diarrheal Disease Rates

Clustering occurs when participants are sampled over time or because multiple participants live in the same household, often resulting in correlated cases of diarrheal disease. Overall, when adjusting for clustering and age of participants, there was a clear association between BSF households and reductions in cases of diarrheal disease, as compared to non-BSF control households. Diarrheal disease reduction was 47%, and is considered statistically significant.

As most diarrhea cases occur in younger children, an effort was made to estimate diarrhea disease risks for the years when

Figure 7: Cases of diarrhea per person per year by household group and visit (estimated from averages over five months)

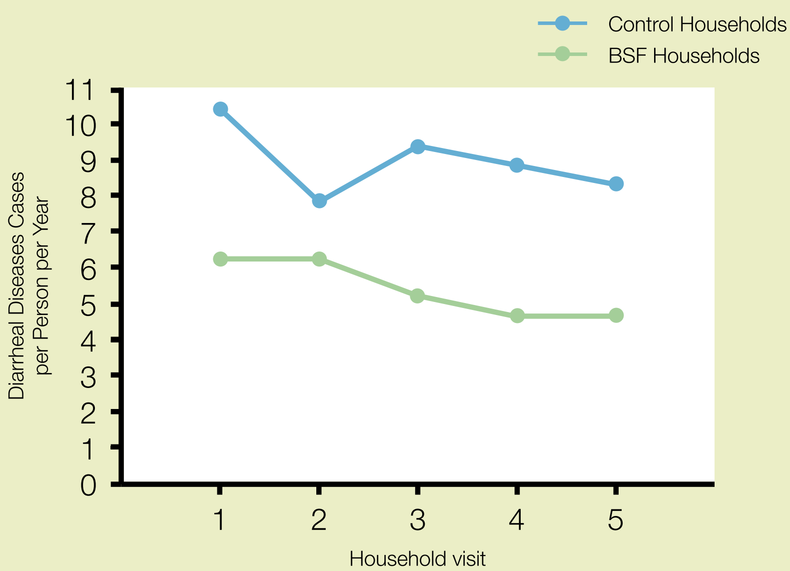


Table 8: Odds ratios and 95% confidence intervals for diarrheal disease (filter as referent group)

Group	**Unadjusted Odds Ratio (OR)**	**95% Confidence Interval**
Age		
All ages	0.56	0.48 - 0.64
<2	0.89	0.63 - 1.24
2 - 4	0.56	0.42 - 0.76
≥5	0.54	0.41 - 0.60
Group	**Adjusted Odds Ratio (OR)[a]**	**95% Confidence Interval**
<2, 2 - 4, ≥5	0.53	0.36 - 0.75

[a]Adjusted for clustering and age

rates of diarrhea would be most impacted in BSF households. Households were first grouped according to age, with the age categories of less than five years, five to 14 years, and 15 years and older, based on age at the time of the first household visit. Stratified odds ratios show a protective effect of the BSF on diarrhea disease occurrence, with reductions of 32%, 46%, and 51%, respectively (data not shown).

The data were stratified by the age categories of less than two years, two to four years, and five years and older. As shown in Table 8, the effect of the BSF on diarrheal disease occurrence in children less than five years of age was greatest in the two to four years age category (44% reduction). The diarrheal disease occurrence between BSF and control households in the less than two years age category was not statistically significantly different, as the 95% confidence interval of the unadjusted odds ratio spans the null value of 1.0. The age category of five years of age and older shows a statistically significant association between BSF and reduced cases of diarrhea.

Both this BSF study and the previous CWP study documented that stored, treated water was subject to recontamination by *E. coli*.

DISCUSSION

Cross Sectional Study

The cross-sectional study results indicate that the BSF has a high uptake rate (88%) and sustained usage for as long as eight years since acquisition. Uptake rate and continued use over time is a major limiting factor to success of household water treatment technologies[21]. An independent appraisal of ceramic water purifiers in Cambodia in 2006 found that ceramic water purifiers (CWPs) were more likely to be used in households that had knowledge of safe water, sanitation and hygiene practices, purchased the technology, used surface water sources for drinking water, and did not use deep wells[11].

In the same study, there was a 2% rate of disuse of CWPs each month after installation, mostly due to ceramic filter breakage and the unavailability of replacement parts, and the average time in use was about two years. The present study identified that the BSF does not show the same rate of disuse that the CWP has shown, likely because it is not prone to breakage or the need for replacement parts.

Uptake rates are also limited for treatment methods that rely on consumable material that require re-purchase, such as chlorine and coagulant-flocculant-disinfectants[21]. For example, 5-13% repurchase proportions have been reported for the PUR disinfectant treatment product in test markets in Guatemala, the Philippines, and Pakistan. Furthermore, continued use of household water chlorination is consistently below 75% based on self-reporting and only about half that amount (<40%) when based on measured chlorine residuals in household water[21]. In contrast, the BSF and other household water filters are durable goods that require one-time acquisition.


There is no shortage of water in Cambodia. It is getting water of good quality that the BSF helps with.

When statistically analyzed, the cross-sectional study found that BSFs are more likely to be used if:

- The household reported that they had received training in operation and maintenance of the BSF. NGOs and other implementers, using developed software and education for behavior modification in implementation programs, have increased the likelihood of continued BSF use after implementation.

- The method for dispensing water from the household storage container was by use of a dipping device. This method is considered a less safe practice as compared to using a tap or pouring stored water, as the dipping device may introduce contamination into the stored water[26]. Use of a dipper may be a reason why BSF-treated and stored water was found to have higher *E. coli* concentrations than BSF-treated water taken directly from the outlet pipe. Proper storage and dispensing behaviors are areas that should be focused on in future BSF training programs. Furthermore, future studies and additional statistical tests assessing this phenomenon are required to fully understand the relationship between household water management and BSF usage.

- A deep well (>10 meters) was used as a water source. Other studies have shown that the BSF often removes iron and therefore may reduce objectionable color, taste, and smell. A household may have chosen to use the BSF for this reason. The use of the BSF associated with deep well use may also be related to the belief that deep wells may contain arsenic and that the BSF may have the capability to remove it. Household reasons for use of the BSF to treat deep ground water were not able to be assessed in this study; asking this in future studies may provide valuable information.

As the cross-sectional study assessing continued BSF use was performed in the rainy season, one explanation for the disuse of the BSF may be that people perceive the quality of rainwater to be higher and therefore do not need to filter their water. Rainwater is unlikely to contain excessive iron or arsenic as deep ground water may, so people may choose to use it because of its better quality, abundance, and ease of access during the rainy season. Factors that were found to be associated with BSF disuse include: inadequacy of filtered water quantity, boiling water as an alternative treatment method, and consuming water directly from the untreated water container or from the source.

All other BSF variables tested, including those regarding operation and maintenance and length of time elapsed between BSF installation in the household and follow-up, were found to not be strongly associated with either continued use or disuse of the BSF. Overall, the cross-sectional study documented high levels of long-term, continued use and acceptability of previously implemented BSFs in Cambodia.

Epidemiological Water Quality and Diarrhea Study

This portion of the study demonstrated that use of a BSF improved the microbiological quality of drinking water at the household level compared to control households. BSF usage resulted in typical reductions of *E. coli* bacteria between 1 and 3 log^{10} and with average reduction of 95%. The CWP independent appraisal[11] showed similar reductions of *E. coli* (95.1%) in treated versus untreated household water. However, both this BSF study and the previous CWP study documented that stored, treated water was subject to recontamination by *E. coli.*

The reasons for simultaneously declining rates of diarrheal disease in intervention and control groups over time are uncertain, but they may be attributable to seasonal fluctuation. Decreases in reported cases of diarrheal disease have been observed in

The protective effect of the BSF is highest for children 2-4 years old.

The age group most impacted by the BSF intervention was the group of two to four year olds, who showed a 44% reduction in diarrheal disease occurrence as compared to control households.

other longitudinal household water intervention studies, including a randomized controlled trial (RCT) and a post-implementation prospective cohort study of concrete BSFs in the Dominican Republic[28,29].In the Dominican Republic RCT, diarrhea rates increased after initially declining, which appeared to be related to changes in rainfall[28]. Furthermore, study fatigue among the participants as the length of the study increased may have lead to less accurate reporting of diarrheal disease over time.

Demographic characteristics of the control and the BSF household groups were very similar, which demonstrates that the comparison of the two household groups was appropriate and study results were consistent with effects attributable to the use of the BSF. However, there was a difference between the two groups regarding hand-washing with soap. In the BSF-user group 83 households (79%) washed their hands with soap, while in the control (non BSF-user) households, only 54 households (53%) did. These results suggest that people in BSF households may have more knowledge or awareness regarding water treatment and other hygiene and sanitation measures than people in non-BSF households in this longitudinal study.

Overall, the use of the BSF in households was associated with a 47% reduction in diarrheal disease as compared to households not using the BSF. In comparison to other studies also measuring health impact based on reduced diarrheal disease, the reduction of diarrhea by the BSF in this study was similar to that observed for the ceramic filters, which documented a 46% reduction of diarrhea cases[11]. Further evidence of the protective effect of the BSF comes from the randomized controlled trial of the BSF in the Dominican Republic, where there was a 47% reduction of diarrheal disease rates for households using the BSF compared to control or non-BSF households[28].

As children less than five years of age were a subgroup of interest in this study, data on diarrheal disease was analyzed by age groups. The age group most impacted by the BSF intervention was the group of two to four year olds, who showed a 44% reduction in diarrheal disease occurrence as compared to control households. For the group of less than two years of age, there was no statistically significant association between filter use and reduced diarrheal illness, despite this group showing the highest rates of diarrheal disease (15.6 cases per person per year). This may be due to limited or no exposure to water from the BSF because mothers may still be breastfeeding. Furthermore, boiling water to mix with powdered formula for babies may be practiced as a more traditional form of water treatment.

Although the BSF may not achieve the same level of indicator microorganism removal as some other POU technologies, it provides substantial reductions of diarrhea in intervention households that are comparable to the reductions achieved by these other POU technologies. Currently, at

least three review papers 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 diarrheal disease reduction results from this post-implementation evaluation of the BSF in Cambodia are consistent with those from this existing literature in documenting the positive health impacts of household water treatment technology interventions.

What about chemical water quality parameters?

Why look at chemicals in water?

A number of chemical contaminants have been shown to cause harmful health effects in humans as a result of long-lasting exposure through drinking-water. Among those are arsenic, fluoride, nitrate and nitrite. Furthermore, iron and manganese are of widespread significance because of their effect on acceptability of drinking water.

While the health benefits of using BioSand filters for the reduction of microbiological contamination have been fairly well documented, little research has focused on the removal of such chemical contaminants through BioSand filters, or how these contaminants may affect the performance of the filters in the field. To address this concern, the performance of a number of BioSand filters installed in rural Cambodia was evaluated over a six month period. This case study was carried out independently from the main work reported in this field note, and only partial results are reported here.

Background to the case study

The study took place in Kesom and Popeal Kaye villages in Kandal Province, Cambodia, and consisted of two parts: Part 1- Initial filter survey and Part 2- Water quality survey of 20 households over time. The initial study consisted of locating all BioSand filters currently installed in these two villages: 81 were found, of which 59 were still in use. Once a filter was located, a survey was conducted with the household and water samples were collected from the untreated source water for the filter and from the treated water leaving the filter spout. From the 59 filters, 20 were chosen to be examined in more detail over a six month period. These 20 households were visited once every two weeks to collect water samples and were asked a short questionnaire regarding filter operation and maintenance. The household visits took place during the dry season. The dry season was chosen

During the study period, on average 11 source waters exceeded the guideline value for combined nitrate and nitrite, while half the source waters exceeded the acute exposure value for nitrite. After treatment both numbers increased.

because during this time households generally use water of poorer quality in their filters--such as well and surface water. During the rainy season, many households use rain water for their filters, which is considered of higher quality.

Water from the filters was analyzed for nitrate, nitrite, ammonia, manganese, iron, fluoride, turbidity, pH, color, total coliforms and *E. coli*. Arsenic was not considered, but a separate field note on arsenic in BioSand Filters is in preparation.

Microbiological results for *E. coli* in this separate study were consistent with the findings from the main study reported in this field note. The most significant findings of this additional research were the results for nitrite and nitrate, and these will be summarized here.

Why are nitrate and nitrite of concern?

The primary health concern regarding nitrate and nitrite is methaemoglobinaemia, or so called "blue-baby syndrome". This is a condition which occurs when nitrite oxidizes iron in the blood and limits the ability of oxygen to be transported around the body causing veins and skin to appear blue.

Bottle-fed infants under 1 year of age are at risk because of the potential intake of nitrate and nitrite from drinking water used to prepare formula, and the relatively high intake of water in relation to body weight.

Given this risk, WHO has established health-based guidelines for nitrate and nitrite in drinking water. The 2007 WHO Guidelines for Drinking-water Quality give the following guideline values:

	Acute exposure (mg/L)	**Long term exposure (mg/L)**
Nitrate (as NO_3-)	50 mg/L (for bottle fed infants)	-
Nitrite (as NO_2-)	3 mg/L (for bottle fed infants)	0.2 mg/L (provisional value)
Combined	$\frac{C\ nitrate}{50} \oplus \frac{C\ nitrite}{3} < 1$ (C is concentration in mg/L)	

Elevated levels of nitrate in surface and ground waters typically result from leaching or runoff from agricultural land (nitrate is mainly used in inorganic fertilizer) or contamination from human or animal waste. Nitrite is formed (and persists) in water under oxygen-poor conditions.

What were the findings?

Results from the 59 filters tested in part 1 of the study are summarized in the table below.

Table 9: Number of filters exceeding the WHO guideline values for nitrate and nitrite (out of 59)

	Source water (in)	Treated water (out)
Nitrate > 50 mg/L	0	0
Nitrite > 3 mg/L	13	17
Nitrite > 0.2 mg/L	22	49
Sum of concentration ratios > 1	14	22

Overall, 39 of the 59 filters saw an increase in nitrate and nitrite after treatment. For the 20 filters studied over a period of 6 months, average values are reported in the table below.

Table 10: Number of filters where average nitrate and nitrite concentrations over a six month period exceed WHO guideline values (out of 20).

	Treated water (out)	
	Using surface water (N=9)	Using well water (N=11)
Nitrate ≥ 50 mg/L	0	0
Nitrite ≥ 3 mg/L	9	8
Nitrite ≥ 0.2 mg/L	9	8
Sum of concentration ratios > 1	9	8

During the study period, on average 11 source waters exceeded the guideline value for combined nitrate and nitrite, while half the source waters exceeded the acute exposure value for nitrite (3 mg/L). As can be seen from the table, after treatment both numbers increased. The average values of nitrate and nitrite in treated water hide large fluctuations though; the lower range for all nitrite measurements and for most nitrate measurements includes zero. This means that while on average 85% of the study households use water where nitrite (or combined nitrate/nitrite) values are exceeded, the exceedance is not constant, and long term effects may be hard to evaluate.

From the findings, it appears that biological nitrification and denitrification may both be taking place in the filter. These are microbially driven processes converting the different forms of nitrogen (ammonia to nitrite and nitrite to nitrate, as well as nitrate to nitrite and nitrite to nitrogen gas). A number of factors could be playing a role in these processes, including source water, frequency of filling and flow rate. However, further work will be required to determine the importance of these and other factors.

Building and using latrines to keep waste out of the environment is one step that can be taken to lower the risk of exposure to nitrate and nitrite.

What are the recommendations?

In the meantime, a number of recommendations can be made to lower the risk of exposure to high levels of nitrate and nitrite.
First to note is that many of the water sources used already have elevated nitrite concentrations prior to treatment; prevention (through awareness raising and following sound construction codes) is an important first step. Keeping waste out of the environment (by building and using latrines, as well as controlling animals) and using well-sited and well protected water sources (e.g. wells sited away from pit latrines and animal pens, constructed with proper lining and using a pump to withdraw water) could prevent many problems.

Keeping human and animal waste out of the environment will help protect water sources.

For infants, we should remember the slogan "breast is best". Avoiding bottle feeding would avoid exposure of infants to nitrite and nitrate. Where bottle feeding cannot be avoided it may be advisable to rely on a trusted source of bottled water. Boiling water would make matters worse, as concentrations of nitrate and nitrite might increase as some of the water evaporates.

Where high levels of nitrite are known to be present in water that is consumed, addition of chlorine (or another oxidant) will convert nitrite to nitrate, which is less harmful. While the combined value for nitrate and nitrite may still exceed the guideline value, the nitrite exposure risk will be reduced. Where possible, testing source waters for nitrate and nitrite may be informative. It is important to realize however, that findings from such testing programs need to be acted upon to be useful.

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Summary And Recommendations

Rural households with limited access to improved water sources can gain alot from using household water treatment.

The BSF is a robust water treatment technology for use in rural Cambodian households. It is capable of effective removal of indicator bacteria, specifically *E. coli*, and BSF-usage in households resulted in a 47% reduction of diarrheal disease as compared to control households. These results are comparable to other recommended household water treatment interventions such as the ceramic water purifier. Moreover, the results of this study demonstrate continued usage rates are higher for the BSF than some other household treatment technologies, which may have increased breakage rates or require replacement of parts. This study also suggests that software programs of the implementing organizations may aid in the disease-reducing effectiveness of the BSF by providing education on the proper use and maintenance of the filter. However, recontamination of stored BSF-treated water remains a challenge to maintaining safe drinking water quality at the household level, as was also previously found for the ceramic water purifier in Cambodia. Overall, the findings of this study provide evidence that the BSF is a promising household POU water treatment option available in Cambodia and other developing countries to achieve sustained access to safe water. While results document long-term BSF use that is effective in improving water quality and reducing diarrheal disease occurrence over a wide range of household and community conditions, further evaluation of the sustained use, water quality improvement, and health impact of BSFs in Cambodia and other countries is recommended as a follow up to this study. Critical performance and program evaluations based on marketing models, consumer behaviors and preferences, and business plans for the BSF, along with other household water treatment technologies, will ensure that these interventions are working effectively to provide safe water, protect users from risks of waterborne disease, achieve high coverage, and result in continued use over long periods of time. If these criteria can be met, scaled up household water treatment and safe storage technologies can be a potentially important contributor to increase sustained access to safe water.

This study also suggests that software programs of the implementing organizations may aid in the disease-reducing effectiveness of the BSF by providing education on the proper use and maintenance of the filter.

Glossary

95% confidence interval (95% CI) a range of values within which the true value of a measurement is expected to occur with 95% probability.

Box-and-whisker plot a graphical representation of a group of numerical data through five number summaries: sample minimum (smallest observation), lower quartile (cuts off lower 25% of data), median (cuts data set in half), upper quartile (cuts off upper 25% of data), and sample maximum (largest observation).

Colony forming unit (CFU) a cluster of bacteria growing on the surface of or within a solid medium; all cells within the colony descend from a single cell and are genetically identical.

Cross-sectional study a type of epidemiological study performed to determine the association between a health outcome and several possible exposure variables at a specific point in time.

Escherichia coli (*E. coli*) a bacterium that is commonly found in the lower intestine of warm-blooded animals; its presence in water indicates the possibility of disease causing microbes and therefore a possible risk to human health.

Geometric mean the average of the logarithmic values of a data set, converted back to a base 10 number; used to reduce the effect of very high or low values which may bias the mean if an arithmetic mean ("average") were calculated.

Log^{10} reduction value (LRV) in this study, a way to describe the reduction in bacterial counts between filter influent (untreated) water and effluent (BSF-treated) water; for example: a 1 log^{10} reduction value corresponds to 90% reduction in microbial concentration.

Longitudinal prospective cohort study a type of epidemiological study that measures the occurrence of disease (e.g. diarrheal disease) within one or more groups having differing exposures (e.g. consume BSF-treated water); exposure information is recorded initially and the specific period of time at risk is forward in time.

Intervention group the group that has or receives the exposure of interest (e.g. BSF users).

Control group the group that is observed under ordinary conditions to provide baseline data to which exposure outcomes can be compared (e.g. BSF non-users).

Odds ratio or unadjusted odds ratio (OR) a measure of the strength of association between two binary outcomes (e.g. using a BSF and relying on a deep well for water supply).

Adjusted OR a type of odds ratio, estimated after any confounding factors (e.g. age) have been taken into account.

p-value the probability of obtaining a result at least as extreme as one that was actually observed in a study, assuming that the null hypothesis (i.e. no difference between the groups) is true example: a p-value of 0.05 corresponds to a 5% chance of a difference (between diarrheal disease rates of BSF-users and BSF non-users) as extreme as the one found, given that there is truly no difference between the two groups.

Point-of-use (POU) treatment technology a type of technology that allows people and communities without access to safe water to improve the water quality by treating it in the home.

Statistically significant a measure of how unlikely it is that a result has occurred by chance alone; often described in terms of p-values.

Turbidity a measure of cloudiness of the water due to the presence of suspended particulates; it is measured as Nephelometric Turbidity Units (NTUs).

Unimproved drinking water sources are water sources that present a larger risk of providing microbiologically contaminated water than improved drinking water sources. Unimproved sources include unprotected dug wells or springs, surface water and vendor-provided water.

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Overall, the findings of this study provide evidence that the BSF is a promising household POU water treatment option available in Cambodia and other developing countries to achieve sustained access to safe water.

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Households have to transport their own filter home after construction.

Further evaluation of the sustained use, water quality improvement, and health impact of BSFs in Cambodia and other countries is recommended as a follow up to this study.

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There is a long way to go still in improving rural living conditions in Cambodia. Better health through better water is one step in the right direction.

What is on the Disc?

The disc included in the pocket below is of the DVD format.
It can be played in any DVD player, and on any Windows computer or Apple computer with a DVD drive.
The DVD contains a video summarizing the findings of the BSF field assessment as described in this field note. One version is in the English language, the other is in Khmer. A soft copy of this field note is also contained on it.

Title	Subject	Language	Duration
Sifting sands: The use of biosand filters in Cambodia	Summary of study results	English	10 minutes
		Khmer	10 minutes

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WSP Field Notes describe and analyze projects and activities in water and sanitation that provide lessons for sector leaders, administrators, and individuals tackling the water and sanitation challenges in urban and rural areas. The criteria for selection of stories included in this series are large scale impact, demonstrable sustainability, good cost recovery, replicable conditions, and leadership.

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