Independent Appraisal of Ceramic Water Filtration Interventions in Cambodia: Final Report

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EXECUTIVE SUMMARY

This study is an independent follow-up assessment of two large-scale implementations of the household-scale ceramic drinking water purifier (CWP) after 2 and 4 years in use. Approximately 1000 household filters were introduced by Resources Development International (RDI) in Kandal Province from December 2003 and 1000+ filters by International Development Enterprises (IDE) in Kampong Chhnang and Pursat provinces from July 2002. The American Red Cross, CIDA, AusAID, UNICEF, and the World Bank Development Marketplace Programme have supplied support to these two NGOs for various parts of the production and distribution cycle of the filters.

In October 2003, IDE completed a field study of the CWPs after one year in use, yielding promising results. The study used bacterial analyses of water samples and user surveys to measure the performance, acceptance and use of CWPs in 12 rural villages. The field study also assessed health improvements, time savings, and expense savings. In August 2005, RDI completed a similar internal study for the filter distribution in Kandal province, although findings from this assessment have not yet been released. The present study follows up on these previous assessments and represents an independent appraisal of the performance of the CWP projects undertaken by IDE and RDI. It is hoped that the findings produced will aid in assessing the water quality and health impacts of the CWP interventions to date and yield useful information on the sustainability of the filters as implemented.

The study was carried out in two parts: (1), a cross-sectional study of households that originally received filters to determine uptake and use rates and associated factors; and (2), a nested longitudinal prospective cohort study of 80 households using filters and 80 control households to determine the microbiological effectiveness and health impacts of the filters in household use. We measured (i) the continued use of the filters over time as the proportion of filters still in use since introduction, and identified factors potentially associated with filter uptake and long term use; (ii), the microbiological effectiveness in situ of the filters still being used, as determined by the log₁₀ reduction values of the indicator bacterium E. coli; and (iii), the health impacts of the filters as determined by a prospective cohort study using data on diarrheal disease prevalence proportions among filter users versus non-users. We also collected a variety of other survey data intended to elucidate successes and challenges facing the long-term sustainability of this intervention in Cambodia. Stratified analyses, logistic regression, and log-risk regression with Poisson extension of generalized estimating equations (GEE) were employed in analysis of cross-sectional and longitudinal data to determine factors associated with long term filter use and effectiveness of filters currently in use.

Major findings are that (i), the rate of filter disuse was approximately 2% per month after implementation, due largely to breakages; (ii), controlling for time since implementation, continued filter use over time was most closely positively associated with related water, sanitation, and hygiene practices in the home, cash investment in the technology by the household, and use of surface water as a primary drinking water source; (iii), the filters reduced *E. coli*/100ml counts by a mean 95.1% in treated versus untreated household water, although demonstrated filter field performance in some cases exceeded 99.99%; (iv), microbiological effectiveness of the filters was not observed to be closely related to time in use; (v), the filters can be highly effective against microbial indicator organisms but may be subject to recontamination, probably during regular cleaning; and (vi), the filters were associated with an estimated 46% reduction in diarrhea in filter users versus non users (RR: 0.54, 95% CI 0.41-0.71).

1 INTRODUCTION

1.1 Water quality and health

An estimated 1.8 million people die every year from diarrheal diseases (WHO 2004a). The majority of the deaths are associated with diarrhea among children under 5 in developing countries, who are more susceptible to the effects of malnutrition, dehydration, or other secondary effects associated with these infections. together, diarrheal diseases are the third highest cause of illness worldwide and the third highest cause of death in children worldwide. These are manifested as various types of diarrheal illnesses, from acute syndromes such as cholera and dysentery to extended or chronic illnesses like hemolytic uremic syndrome and Brainerd diarrhea. According to Cambodian national health statistics for the year 2000, the prevalence of childhood diarrhea (children aged 0-60 months) is 18.9%, based on a 14-day recall period. Prevalence in and around Phnom Penh is 24.4% (NIS 2000). National data on diarrhea for older children and adults have not been collected, as children under 5 years represent the most at-risk group and therefore have been the focus of surveys. There were an estimated 309,933 reported cases of diarrhea (including dysentery) in Cambodia in 2000, out of a population of approximately 13 million (WHO 2004b). Data on diarrheal disease morbidity and mortality is often underreported, however.

Prüss et al. (2002) estimated that 4.0% of all deaths and 5.7% of the global disease burden are attributable to inadequate water, sanitation, and hygiene, largely due to diarrheal diseases (WHO 2004a). An unknown percentage of the diarrheal disease burden is due solely to unsafe drinking water, because the viral, bacterial, and parasitic microbes causing diarrheal disease may also be transmitted through contaminated food, hands, fomites, or other routes. We do know, however, that water quality plays an important role in the risk of diarrheal diseases and access to safe water is a major determinant of diarrheal disease rates. Diarrheogenic organisms generally originate in fecal matter and are transmitted through the fecal-oral route of infection (Curtis et al. 2000).

1.2 Cambodia and household water treatment

For the estimated 66% of Cambodians without access to improved drinking water sources (UNICEF 2005) and the potentially much greater percentage without consistent access to microbiologically safe water at the point of use, household-based water treatment and safe storage can play a critical role in protecting users from waterborne illness. Surface water in Cambodia is plentiful but often of very poor quality, due to inadequate or nonexistent sanitation in rural areas. Only 16% of Cambodians have access to adequate sanitation facilities (ibid.). Cambodia is also subject to heavy flooding, particularly in the late summer and fall as the southwestern monsoon peaks. Deforestation in the Mekong river basin, the longest river in Southeast Asia, has contributed to worsening floods in the region. This perennial problem leads to increasingly degraded and unsafe surface water sources, which contributes to the spread of waterborne diseases. Cholera, for example, is endemic in Cambodia, with more than 1000 cases reported per year and major outbreaks reported in 1998 and 1999 (WHO 2006). Some groundwater sources in the country are also known to contain high levels of naturally occurring arsenic. Arsenic in the groundwater is an especially urgent problem in parts of the lower Mekong delta region where there is a high population density. Surface water (often of poor microbiological quality) and rainwater catchment (susceptible to contamination during storage) are the principal alternatives to arseniccontaminated groundwater.

Due to the poor quality of available drinking water sources and the lack of centralized systems for delivering safe water to households, Cambodia has become a major locus for household water treatment research and implementation. An estimated 200,000 people (1.5%) already use some form of filtration (sand or ceramic) or chemical treatment at the household level. In addition, many more treat some or all household drinking water using coagulants, traditional cloth filters, or boiling.

Household-based water treatment and safe storage can provide users with protection against waterborne pathogens where safe water sources and other treatment options are scarce. The reality for most Cambodians today is that they must collect water, store it for use in the household, and treat and protect it themselves if they are to have safe water. A recent meta-analysis of field trials established that household-scale water quality interventions can be effective in reducing the burden of diarrheal disease, with average reductions of 39% (95% confidence interval of 19% - 54%) in users versus non-users (Fewtrell et al. 2005). Despite their widespread promotion and use in Cambodia, ceramic water purifiers, which are porous ceramic pot filters for point-of-use water treatment in the home, have never been independently evaluated for their ability to reduce waterborne diarrheal disease. This report presents the results of such a study.

1.3 Study overview

An emerging point-of-use treatment technology is the ceramic water purifier (CWP), a household-scale, porous ceramic filter. Some CWPs have recently been found to not only improve water quality at the point of use but also reduce household diarrheal disease (Clasen et al. 2004; Clasen et al. 2006). The ceramic filter intervention evaluated in this study, however, has not been well characterized for its performance in the field to reduce diarrheal diseases. Its effectiveness over long periods of regular use in the field has also not been well studied previously. Knowledge of these factors is critical and prerequisite to successful scale-up and responsible investment in the technology.

This study is an independent follow-up assessment of two large-scale implementations of the household-scale ceramic drinking water purifier (CWP) after 2 and 4 years in use. Approximately 1000 household filters were introduced by Resources Development International (RDI) in Kandal Province beginning in December 2003 and 1000+ filters by International Development Enterprises (IDE) in Kampong Chhnang and Pursat provinces beginning in July 2002. The American Red Cross, CIDA, AusAID, UNICEF, and the World Bank Development Marketplace Programme have supplied support to these two NGOs for various parts of the production and distribution cycle of the filters.

In October 2003, IDE completed a field study of the CWPs after one year in use, yielding promising results. The study used bacterial analyses of water samples and user surveys to measure the performance, acceptance and use of CWPs in 12 rural villages. The field study also assessed health improvements, time savings, and expense savings. In August 2005, RDI completed a similar internal study for the filter distribution in Kandal province, although findings from this assessment have not yet been released. The present study follows up on these previous assessments and represents an independent appraisal of the performance of the CWP projects undertaken by IDE and RDI. It is hoped that the findings produced will aid in assessing the water quality and health impacts of the CWP interventions to date and yield useful information on the sustainability of the filters as implemented.

In this independent assessment we measured the following parameters:

- (i) the continued use of the filters over time as the proportion of initial filters still in use since introduction, and the identification of factors potentially associated with filter uptake and long term use;
- (ii) the microbiological effectiveness *in situ* of the filters still being used, as determined by the log₁₀ reduction values of the indicator *E. coli*; and
- (iii) the health impacts of the filters as determined by a prospective cohort study using data on diarrheal disease prevalence among filter users versus non-users.

We also collected a variety of other survey data intended to elucidate factors influencing implementation success and the challenges facing the long-term sustainability of this intervention in Cambodia. The study was carried out in two parts: (1), a cross-sectional study of households that originally received filters to determine uptake and use rates and associated factors; and (2), a nested longitudinal prospective cohort study of 80 households still using filters and 80 control (non-filter) households to determine the microbiological effectiveness and health impacts of the filters in household use. Stratified analyses, logistic regression, and log-risk regression with Poisson extension of generalized estimating equations (GEE) were employed in analysis of cross-sectional and longitudinal data to determine factors associated with long term filter use and effectiveness of filters currently in use.

1.4 The Intervention

The CWP is a flower pot-shaped, gravity flow, porous ceramic filter device intended to treat drinking water on the household scale. Water is poured through the porous ceramic pot into a receiving container that stores treated water, with treated water dispensed via a tap. Such filters are widely used in developing countries for treating water in the household. The physical design of the Cambodian ceramic water purifier (CWP) is based on the ceramic water filters (called Filtrón in Latin America) developed by Potters for Peace, an international NGO that promotes the use of locally-produced ceramics for water treatment in developing countries. The filters are often coated with various forms of silver to provide bacteriostasis and increase microbiological effectiveness. Flow rates are generally 1-3 liters per hour when the filter is full (decreasing thereafter as head lowers), but varies by manufacturer and with water quality. Filters are cleaned by lightly scrubbing the surface when flow rate is reduced, usually due to the use of turbid water. The recommended useful life of the filter varies by manufacturer, but most recommend replacement of the ceramic filter element or periodic recoating of the filter with silver to ensure maintained effectiveness over time, usually every 1-2 years. There are little data, however, on the extent of microbiological effectiveness over long term periods of use, or how effectiveness changes over time in use. The ceramic filters themselves can be used for long periods, provided they do not break. Lantagne (2001) found that some filters in Central America were still being used after 5+ years in the field. The CWPs under study here are from two NGO manufacturers in Cambodia, International Development Enterprises (IDE) and Resource Development International (RDI). Their designs, production methods, silver treatment methods, and quality control steps are distinct but similar. This study was not intended to sort out the better method of production or effectiveness between the technologies They were assumed similar enough to be comparable under field themselves. conditions.

2 METHODS AND MATERIALS

2.1 Cross-sectional study

For eligible and consenting households, data were recorded for the breakage (and other failure) rate and usage rate of the filters during the intervening years since introduction as a measure of sustainability. Households originally receiving filters and training in their use were interviewed to determine the causes of breakage, other failures or disuse, and other important covariates thought to be associated with filter uptake and use.

2.1.1 Study sites

Filters were implemented originally in three provinces in Cambodia. Interventions in Kampong Chhnang and Pursat provinces were carried out by International Development Enterprises (IDE) from July 2002. Resource Development International (RDI) conducted implementation from December 2003 in Kandal province. Households included in the study were located in 13 rural villages in the three provinces.

2.1.2 Definition of study population and selection of households

The study population consisted of all households originally receiving filters as part of the two large intervention projects in the three provinces of Kandal (n=1000), and Kampong Chhnang and Pursat (n=1000). Complete lists of households who received filters as part of the original interventions were compiled from information provided by the implementing NGOs. GPS coordinates or other locating details were available for some of the households. A master list of all households in the three project areas was compiled, and households were selected at random using a random numbers table. Two hundred (200) households originally receiving filters were randomly selected for follow up visits in each of the three provinces.

Inclusion criteria for the cross-sectional survey of households were: (i) being a family or other household communal unit that received a CWP through the implementation program, (ii) a family or other household communal unit still living at the same location where they received the filter, and (iii) voluntary willingness to participate in the survey. Exclusion criteria for the cross-sectional survey were (i) the family or other household communal living unit no longer lives at the original location or (ii) unwillingness to participate in the survey.

2.1.3 Data collection

All survey instruments were prepared in both English and Khmer prior to use in the study. They were pre-structured and pre-tested (by back-translation from Khmer to English and use in pilot interviews). The project manager, project coordinator, and health specialist took responsibility for preparing all survey instruments. Surveys used simple, straightforward language with predominantly closed (multiple choice) questions. Individual survey questions were prepared in some cases based on input from previous questionnaires used by RDI and IDE in their own internal assessments of the CWP interventions. This was done so that the data produced in this study would be consistent and comparable to the data produced in the previous internal assessments by these organizations.

The data collection (field) team was composed of 4 trained interviewers who were native speakers of Khmer and had related experience in community health data collection. During the months of February and March 2006, the data collection team visited households that had originally received filters. The cross sectional survey included data collection on a variety of covariates potentially influencing the continued use of the filters under a variety of conditions and during up to 45 months of use. These

included water use and handling practices and socio-economic measures, as well as elapsed time since implementation of the filter. Reasons for and estimated date of filter disuse were also solicited from respondents. The data on household water use and handling practices was gathered during an interview with the household head, defined as the adult caregiver for the children, usually an adult female. A wealth index measure of the household was used. It was based on access to electricity and an inventory of household possessions indicative of relative wealth. Data on the method of gathering water from the household storage container and on the presence of soap in the household was gathered by demonstration to the interviewer.

2.1.4 Data entry and management

Data were collected via verbally administered questionnaires and recorded onto hard copy data sheets. Households and individuals were assigned a unique code number as an identifier. During sample collection, household surveys and water samples were identified by a unique household code number assigned by the data collection team. Data were collected and original data sheets were stored at the laboratory office in bound notebooks in a locked cabinet with access only to specifically authorized project staff. Surveys and water quality data were entered regularly into a Microsoft Excel spreadsheet or Microsoft Access database and copied into Stata (version 8), excluding the direct personal identifiers of the study participants. All data were entered twice to ensure consistency and accuracy of data input.

2.1.5 Analytical approach

Observational and survey data collection at household visits were transcribed from questionnaires and double-entered into Microsoft Access. They were then exported to Microsoft Excel and Stata for analysis. Logistic regression was performed using filter use at time of follow up as a binary outcome variable, with covariates tested for independent associations with the outcome. Logistic regression analysis was also performed controlling for time since implementation, coded as a categorical variable with time in 6-month increments.

The main outcome variable in the cross sectional survey was filter use at the time of follow up. Criteria for filter use were that the household head indicated regular daily use of the filter, that the filter appeared to be in good working order, and that the inside of the filter contained water or was damp from recent use. Filters that were broken, being used for another purpose, or completely dry were considered out of use.

2.2 Longitudinal study

A longitudinal study was conducted using eligible participants from the cross-sectional cohort and additional households recruited from the same area. Our approach in determining the health effects of the filters among users in the households that had them was the reduction of diarrhea relative to a reference group in households that didi not have filters. This was a prospective cohort study design of 80 households currently using filters and 80 households not using filters. Each household currently using a CWP (intervention, as determined by data collected in the cross-sectional survey) enrolled in the follow-up study was matched with a non-intervention (control) household (without a filter) based on area or geolocation (<1 km distant), water source, and approximate wealth. An additional 25 intervention households were recruited in Kampong Chhnang to increase the sample size to 80 households in each group. This was because an insufficient number of eligible households were identified in Kampong Chhnang & Pursat provinces using random selection of households from all households originally receiving filters. Participating households were visited three times for water sample collection and

analyses. Data on diarrheal disease was gathered on two of these occasions. Data on water use and handling practices, sanitation and hygiene, and other potentially important covariates also were gathered. Stratified analyses and log-risk regression with Poisson extension of generalized estimating equations (GEE) were employed in analysis of time series data to determine the effect of the filter and water quality in the home on diarrheal disease prevalence. Risk ratios for diarrheal disease based on a 7-day recall period among members of households with (intervention) and without (non-intervention or control) filters were used as the main outcome. Descriptive analyses of the intervention's impacts on household water quality based on levels of *E. coli* bacteria and turbidity were also performed.

2.2.1 Definition of study population and selection of households

The subjects were persons who live in households using a CWP and an approximately equal number of matched (on geographic location, socioeconomic status estimate, and drinking water sources) households not using CWPs in Kandal, Kampong Chhnang, and Pursat provinces. Participating households were randomly selected from all eligible households within the three provinces. As a goal of the study was to assess effectiveness of filters over some time in use, the random selection of households was weighted within provinces to ensure that the cohort would be representative of filters in use for 0-4 years. Because interventions in each province took place during known periods, weighting the randomization by province (50% in Kandal, 25% in Kampong Chhnang, 25% in Pursat) produced eligible households with filter in use over the 4 years. Had eligible households using filters been randomly selected from all those eligible households encountered during the cross- sectional study, this would have weighted the cohort toward Kandal province and the newer interventions, as those households were much more likely to still be using their filters.

Inclusion criteria for the longitudinal study were that households (i) were willing to voluntarily participate, (ii) store water in the home, (iii) currently use a CWP in a household that originally received one (intervention household), (iv) are located in the same community, do not have and never received a CWP and use the same or similar water sources for household water as CWP households (reference or control household), (v) have a child of age 5 years or less as a household member at the first household visit, and (vi) did not use commercial bottled water as the primary source of household potable water. Exclusion criteria were: (1) unwillingness to participate, (ii) no child less than 5 years of age in the household at the time of the first household visit, (iii) primary or exclusive use of commercial bottled water as potable water in the home, and (iv) unavailability of a consenting matched household in the other study group.

2.2.2 Inducements to participate

All subject households are provided with *gratis* water filters and storage containers upon completion of the study (after household interviews and water samples are collected) as part of their willingness to participate in the study. Households in Kandal will receive equivalent filters from RDI and households in Kampong Chhnang and Pursat will receive IDE filters. In addition, all study subjects were provided with oral rehydration salts and instructions for use at no cost at each household visit by the study team. Distribution of the filters will be completed by 1 June, 2006.

2.2.3 Ethics

Informed consent was obtained from the appropriate family member. This was the head of household (defined as the primary caretaker for the children, responsible for household work and either responsible for or knowledgeable of household water

management practices, usually an adult female) who acted as the main correspondent for the home in subsequent visits. This person was identified by asking to speak with the person who is the primary care taker and in charge of household responsibilities such as water management, cooking, cleaning, etc. The consent form was translated into Khmer and then back translated into English, and piloted to ensure clarity before use in the field. Subjects read or were read the form in Khmer by project staff. Participating householders were presented with a narrative description of the project (both written and orally) and asked to participate in the study entailing up to three household visits by the project team. Participants then signed the consent form, representing consent for all of the persons in the house. This project and its means for obtaining informed consent from participants were reviewed and approved by the Biomedical Institutional Review Board on Research Involving Human Subjects, Office of Human Research Ethics, The University of North Carolina at Chapel Hill, USA, and the Ministry of Rural Development, Kingdom of Cambodia.

2.2.4 Data collection

All survey instruments were prepared in both English and Khmer prior to use in the study. They were pre-structured and pre-tested (by back-translation from Khmer to English and use in pilot interviews). The project manager, project coordinator, and health specialist took responsibility for preparing all survey instruments. Surveys used simple, straightforward language with predominantly closed (multiple choice) questions. Individual survey questions were prepared in some cases based on previous questionnaires used by RDI and IDE in their own internal assessments of the CWP interventions. This was done so that the data produced in this study would be consistent and comparable to the data produced in the previous internal assessments by these organizations.

The data collection (field) team was composed of 4 trained interviewers who were native speakers of Khmer and had related experience in community health data collection. During the months of March to April 2006, the data collection team visited participating households. Households were visited three times by the field data collection team. The head of the household was asked to provide a 7-day recall of diarrheal disease for herself and any member of her household. Diarrhea was clearly defined as three or more loose or watery stools in a 24-hour period or any stool with the presence of blood, based on World Health Organization definitions.

Water samples of 250 ml volume were taken from each household in the study to determine the effectiveness of the filters in reducing the concentrations of microbes present in drinking water sources. Samples were kept cool and transported as soon as possible to the laboratory in Kien Svay, where analysis was performed as soon as possible, usually within 24 hours. Total coliforms and Escherichia coli were quantified in water samples using membrane filtration (MF) techniques followed by incubation on selective media and reported as colony-forming units (CFU) per 100ml. All samples were processed in duplicate using a minimum of two dilutions and positive and negative controls. Households in the intervention group were sampled for two types of water: untreated, stored household water and treated water as it was delivered via the filter tap. Samples from the control households were taken for analysis as well, and included their current drinking water and untreated water, if they use another water treatment method (e.g., boiling). Turbidity of water samples was measured in triplicate using a turbidimeter (Hack Pocket®) and the average values reported as NTU. pH of water samples also was measured in the laboratory using an electronic pH meter (Thermo Orion 290A+). Three rounds of water samples were taken from each study household over the 10 week sampling period (February 10 – April 21).

In addition to the household data collected on health and water quality, additional data on potential covariates were collected during household visits. Questions were asked to determine compliance with the household water intervention (water acquisition, treatment, storage and use practices) and to document sanitation and hygiene conditions and practices. A survey of sustainability measures (e.g., frequency of filter use and cleaning, time involved in use of the filter, perception of convenience, filter element replacement experience, etc) was also administered to households using CWPs. These data can potentially provide important insight into the success of the intervention to date in the households where it is still being used successfully. The collected hygiene, sanitation, and water use data can be correlated with water quality and health data as potential covariates in the subsequent analysis. Data on willingness to purchase and appropriateness of costs for additional filters in the future were also collected using a willingness-to-pay approach.

2.2.5 Data entry and management

Survey data were collected via verbally administered questionnaires and recorded onto hard copy data sheets. Households and individuals were assigned a unique code number as an identifier. During sample collection, household surveys and water samples were identified by a unique household code number assigned by the data collection team. Data were collected and original data sheets were stored at the laboratory office in bound notebooks in a locked cabinet with access only to specifically authorized project staff. Surveys and water quality data were entered regularly into a Microsoft Excel spreadsheet or Microsoft Access database and copied into Stata Release 8 (Stata Corporation, USA), excluding the direct personal identifiers of the study participants. All data were entered twice to ensure consistency and accuracy of data input.

2.2.6 Analytical approach

Data collected for water quality and from initial household surveys were initially analyzed using stratified analyses to identify trends (microbial concentrations in water as well as physical-chemical water quality and diarrheal disease prevalence measures). Longitudinal data were analyzed for differences between the two household groups, those with CWPs (intervention) and those without (non-intervention). Poisson regression models were used to analyze diarrhea prevalence proportions in users as compared to non-users of the filter. Potentially confounding variables in the analytical model were (i) those that affect the exposure in the study population (e.g., factors associated with continued use of the filter); and (ii) those that are risk factors for the outcome of diarrheal disease in the control group. Confounders were identified based on an a priori changein-effect criterion of 10%. To control for clustering within households and within individuals over time, a Poisson extension of generalized estimating equations (GEE) was employed in log-risk regression. To determine correlation of water quality with health impact, water quality data was analyzed initially as a continuous variable and subsequently as a categorical variable representing increasing levels of microbial exposure (according to the WHO classification of risk level as indicated by E. coli concentrations), with the binary (positive or negative) outcome of diarrheal disease in the previous 7 days measured for each individual.

Health effect measures reported are the prevalence proportion of diarrheal disease in both study groups and the risk ratio (RR) computed as the risk of diarrheal disease among the cohort using the intervention divided by the risk of diarrheal disease experienced by the control group, adjusted for clustering within individuals over time and within households. Because households are not observed for an extended period (only

2 follow-up visits), measures of disease incidence cannot be estimated; establishing time-at-risk experienced by each family member was not possible. Prevalence proportions can be used to approximate incidence rates if incidence rates and disease duration in the two study groups are assumed constant, however. Longitudinal prevalence of diarrheal disease in children has been shown to be a powerful indicator for mortality in children in developing countries (Morris et al. 1996).

3 RESULTS: CROSS-SECTIONAL STUDY

3.1 Study participants and households

A total of 506 households with an average of 5.9 people per household were included in the cross sectional study (total number of persons = 2965, 52% female). Basic demographic and proxy data on household wealth was gathered and households were assigned to one of three groups: 17 households (3%) were relatively wealthy, 254 (50%) middle, and 235 (46%) poor.

A number of households (64, 11%) could not be found as GPS or other locating information was not included with the original implementation records in Kampong Chhnang and Pursat. Other households (29, 5%) had moved during the intervening years. One household (<1%) refused to participate in the study. Informed consent was obtained from 178 households in Kandal, 132 households in Kampong Chhnang, and 196 households in Pursat province. The province-weighted randomization process created a weighted overall sample toward Pursat and Kampong Chhnang. This is because filters were in use there for up to 4 years and therefore a lower number of households maintaining regular filter use was expected. Because subsequent water quality and health data collection would examine relationships between health effects and microbiological effectiveness as a function of time since implementation in this cohort, our intention was to ensure adequate numbers of in-use filters were included from the older intervention project.

Table 3.1 presents a summary of data collected on all households, stratified by filter use status and province. Table 3.2 presents data collapsed over provinces and estimated odds ratios. Odds ratios were calculated based on all households using filters versus those not currently using filters (collapsed across province), adjusted for time in use as coded in 6 month increments. Filters that have been in use for 0 to the end of 5 months were coded as 0-5 months, and so on. Odds ratio estimates greater than one indicate a positive association between the factor and filter use; odds ratios less than one indicate a negative association.

3.2 Water use and handling practices

As households were recruited from across three provinces and several villages, a wide variety of water use and handling practices were observed, all of which varied by province (tables 3.1 and 3.2 contain stratified data for measured parameters). During the study period of February – April (dry season), 243 households (48%) reported using surface water (lake, pond, river, stream, *prek*, *boeng*, or canal) as a primary source of drinking water; 79 (16%) reported use of a deep well (defined here as >10m in depth); 152 (30%) used a shallow well; 39 (8%) used stored rainwater from the previous rainy season; and 9 (2%) of households reported using bottled drinking water. The distribution of prevalent drinking water sources varied with the region. Respondents were asked to estimate the distance to the primary drinking water source: 340 (67%) of sources were within 100m, 128 (25%) were between 100-500m, and 38 (8%) were >500m away.

Every household encountered in the study used one or more water storage containers to store water inside or (more commonly) outside the home; 164 (32%) used one or more uncovered containers. Containers were usually ceramic or concrete traditional vessels. Respondents were asked to demonstrate the usual method of collecting water from the container for drinking. A total of 220 (43%) of the respondents dipped hands or a cup directly into the container, while 286 (57%) used a tap or a dipper which was then poured out into a cup for drinking.

	Using filt	ter ^a at time	of follow	Not us	sing filter at	time of	
	up		1. \	follow up			
		56 household			50 househol		
Province	Kandal n=115	Kampong Chhnang n=10	Pursat n=31	Kandal n=63	Kampong Chhnang n=122	Pursat n=165	All n=506
Soap observed in							
household ^b							
Yes	87(75%)	8(80%)	24(77%)	52(83%)	75(61%)	93(56%)	339(67%)
No	28(24%)	2(20%)	7(23%)	11(17%)	47(36%)	72(44%)	167(33%)
Purchased filter ^c	00/050/	0	44/450/)	F7/000/\	0(00()	40(040()	044/400/)
Yes No	98(85%) 17(15%)	0	14(45%) 17(55%)	57(90%) 6(10%)	2(2%)	40(24%)	211(42%) 295(58%)
Poverty index ^d	17(15%)	10(100%)	17(55%)	6(10%)	120(98%)	125(76%)	295(56%)
Wealthy	4(3%)	0	0	7(11%)	0	6(4%)	17(3%)
Middle	82(71%)	3(30%)	18(58%)	46(73%)	32(26%)	73(44%)	254(50%)
Poor	29(25%)	7(70%)	13(42%)	10(16%)	90(74%)	86(52%)	235(46%)
Access to sanitation ^e		,		` /	7	, ,	`
Yes	85(74%)	2(20%)	15(48%)	41(65%)	16(13%)	35(21%)	194(38%)
No	30(26%)	8(80%)	16(52%)	22(35%)	106(87%)	130(79%)	312(62%)
Reported receiving health education ^f							
Yes	23(20%)	3(30%)	5(16%)	11(17%)	42(34%)	30(18%)	114(23%)
No	92(80%)	7(70%)	26(84%)	52(83%)	80(66%)	135(82%)	392(77%)
Covered water	(,	(,	-(- ()	(,	(
storage container							
Yes	85(74%)	5(50%)	28(90%)	44(70%)	55(45%)	125(76%)	342(68%)
No	30(26%)	5(50%)	3(10%)	19(30%)	67(55%)	40(24%)	164(32%)
Wash hands w/soap? ⁹	00(2070)	0(0070)	0(1070)	10(0070)	0. (00,0)	(= . / 0)	101(0270)
Yes	62(54%)	3(30%)	11(35%)	43(68%)	28(23%)	29(18%)	176(35%)
No	53(46%)	7(70%	20(65%)	20(32%)	94(77%)	136(82%)	330(65%)
Main drinking water							
sources during study							
(dry season) ^h							
Surface water	75(65%)	0	23(74%)	40(63%)	5(4%)	100(61%)	243(48%)
Groundwater	40(400()	0	0(00()	0/50/\	40/000/	00(400()	70(400()
Deep well (>10m) Shallow well	12(10%) 9(8%)	0 10(100%)	2(6%) 8(26%)	3(5%) 4(6%)	40(33%) 69(57%)	22(13%) 52(32%)	79(16%) 152(30%)
Rainwater	23(20%)	0	0	13(21%)	09(37 %)	32(32 %)	39(8%)
Bottled water	2(2%)	Ö	0	1(2%)	Ö	6(4%)	9(2%)
Observed method of	(11)	-	-	(/	-	- (/	- (/
drawing water ⁱ							
Use hands	53(46%)	5(50%)	12(39%)	25(40%)	59(48%)	66(40%)	220(43%)
Pour or tap	62(54%)	5(50%)	19(61%)	38(60%)	63(52%)	99(60%)	286(57%)
Months since							
implementation ^J							
0-5	49(43%)	0	0	7(11%)	1(1%)	0	57(11%)
6-11	11(10%)	0	1(3%)	2(3%)	0	1(1%)	15(3%)
12-17	16(14%)	0	0	11(17%)	1(1%)	4(2%)	32(6%)
18-23 24-29	30(26%) 5(4%)	1(10%) 1(10%)	1(3%) 8(26%)	30(48%) 5(8%)	0 7(6%)	1(1%) 18(11%)	62(12% 43(8%)
30-35	3(3%)	0	3(10%)	2(3%)	5(4%)	22(13%)	35(7%)
36-41	0	2(20%)	9(29%)	0	46(38%)	66(40%)	123(24%)
42-48	0	7(70%)	7(23%)	0	45(37%)	51(31%)	110(22%)
a Regular (daily) use as deter	mined by inter	vious and by vic	ual increation	Dorcontagos	may not add to	100% due to re	unding

a. Regular (daily) use, as determined by interview and by visual inspection. Percentages may not add to 100% due to rounding.

Table 3.1. Cross sectional study data summary.

b. Respondents were asked to demonstrate that soap was present in the household.
c. Any price. Prices paid for filters ranged from 1000 – 10,000 riel (0.25 – 2.50 USD). Actual cost is \$4-\$8 USD.

d. Based on access to electricity and inventory of household possessions indicating relative wealth.

e. Shared or own latrine.
f. Water, health, hygiene, or sanitation education from any source (school, NGO, media, etc).

g. Users who responded that they did wash hands "always" with soap at critical points such as after defecating. h. Multiple answers possible.

ji Respondents were asked to demonstrate their usual method of gathering water from the storage container.

j. Based on NGO records from the original installation, the manufacturing date stamped onto the filter, or users' estimates.

	Using filter ^a at time of follow up (156 households)	Not using filter at time of follow up (350 households)	OR (95% CI) Adjusted ^b
Soap observed in household ^c Yes No	119 (76%) 37 (24%)	220 (63%) 130 (37%)	1.7 (1.0-3.0)
Purchased filter ^d Yes No	112 (72%) 44 (28%)	99 (28%) 251 (72%)	2.1 (1.2-3.7)
Poverty index ^e Wealthy Middle Poor	4 (3%) 103 (66%) 49 (31%)	13 (4%) 151 (43%) 186 (53%)	0.77 (0.50-1.2)
Access to sanitation ^t Yes No	102 (65%) 54 (35%)	92 (26%) 258 (74%)	2.4 (1.5-4.0)
Reported receiving health education ^g Yes No	31 (20%) 125 (80%)	83 (24%) 267 (76%)	0.74 (0.42-1.3)
Covered water storage container Yes No	118 (76%) 38 (24%)	224 (64%) 126 (36%)	1.6 (0.94-2.7)
Wash hands w/soap? ^h Yes No	76 (49%) 80 (51%)	100 (29%) 250 (71%)	1.6 (1.0-2.6)
Main drinking water sources during study (dry season) ⁱ Surface water Groundwater Deep well (>10m) Shallow well Rainwater Bottled water	98 (63%) 14 (9%) 27 (17%) 23 (15%) 2 (1%)	145 (41%) 65 (19%) 125 (36%) 16 (5%) 7 (2%)	1.7 (1.1-2.7) 0.38 (0.18-0.79) 0.91 (0.50-1.7) 1.4 (0.64-3.0) 0.53 (0.08-3.4)
Observed method of drawing water ^j Use hands Pour or tap	70 (45%) 86 (55%)	150 (43%) 200 (57%)	0.90 (0.56-1.4)
Months since implementation ^k 0-5 6-11 12-17 18-23 24-29 30-35 36-41 42-48	49 (31%) 12 (8%) 16 (10%) 32 (21%) 14 (9%) 6 (4%) 11 (7%) 14 (9%)	8 (2%) 3 (1%) 16 (5%) 31 (9%) 30 (9%) 29 (8%) 112 (32%) 96 (27%)	0.56 (0.50-0.63) (per 6 month increase)*

a. Regular (daily) use, as determined by interview and by visual inspection. Percentages within strata may not add to 100% due to rounding.

Table 3.2. Data summary and estimated odds ratios for covariates with the outcome of filter use at the time of follow up. Odds ratios are adjusted for time elapsed since implementation.

b. Odds ratio estimates adjusted for time since implementation, coded as a categorical variable in 6 month blocks, except *.

c. Respondents were asked to demonstrate that soap was present in the household.

d. Any price. Prices paid for filters ranged from 1000 – 10,000 riel (0.25 – 2.50 USD). Actual cost is \$4-\$8 USD.

e. Based on access to electricity and inventory of household possessions indicating relative wealth.

f. Shared or own latrine.

g. Water, health, hygiene, or sanitation education from any source (school, NGO, media, etc).

h. Users who responded that they did wash hands "always" with soap at critical points such as after defecating.

i. Multiple answers possible.

j. Respondents were asked to demonstrate their usual method of gathering water from the storage container.
 k. Based on NGO records from the original installation, the manufacturing date stamped onto the filter, or users' estimates.

3.3 Sanitation and hygiene practices

Of the 506 households included in the study, 194 (38%) had access to sanitation (either the household's own or a shared latrine). None of the households were connected to a conventional sewerage system. Sanitation access varied greatly by location; in Kandal, 71% of households had access to a latrine, versus 14% in Kampong Chhnang and 26% in Pursat. The difference here is due to the fact that study sites in Kandal were relatively wealthier and also because increasing access to sanitation had been one of RDI's efforts linked to CWP implementation in the villages of Slap Ta Oun, Tareap/Doan Saa, and Prek Thom. Therefore, households who had received filters were more likely to have received sanitation access as well. Respondents were asked whether and how often they and members of their family washed their hands, for example after defecating and before preparing food. 175 (35%) of respondents indicated that hand washing was practiced by all members of the household "always" at critical points with soap and Respondents were also asked to demonstrate that there was soap in the household at the time of the visit; 339 households (67%) were able to produce it. Additionally, 114 respondents (23%) reported receiving health education relevant to water, sanitation, and hygiene. Of these, 18 (16%) reported receiving information from family and friends, 87 (76%) from a health worker or NGO, 78 (68%) from radio, 103 (90%) from television, and 1 (1%) from school. Ninety-two (92%) percent of study respondents indicated that they thought diarrhea is a serious and potentially fatal illness Eighty-one (81%) percent of respondents reported that water is an important route of disease transmission.

3.4 Filter use

Respondents were asked whether their CWP was functional and being used, and this was verified by visual inspection. Criteria for visual inspection were that filter was damp from recent use, was not being used for another purpose, and was in good working order at the time of the visit. Of 506 households in the study, 156 (31%) were using the filter regularly at the time of follow up, although the proportion in use was strongly associated with the length of time elapsed between filter installation in the household and follow up (table 3.2). If the filter was in regular (daily) use by the household, users were asked several questions about filter use such as times filling it per day and uses. Users reported filling the filter an average of 1.8 times per day and cleaning it 2.3 times per week. 133 (86%) of households reported using the filter for drinking water only.

Respondents were also asked where they obtained the filter, whether the filter in the household at the time of the visit is a replacement filter, how much the filter cost, where they would go to buy a new filter if desired, and what an appropriate ("fair") price would be for new filters. A small number of households reported purchasing additional filters after a breakage: 11 (6%) in Kandal, 4 (3%) in Kampong Chhnang, and 6 (3%) in Pursat. Of 281 households with disused filters responding, 120 (43%) households reported a willingness to purchase an additional filter: 24 (73%) in Kandal, 20 (19%) in Kampong Chhnang, and 76 (53%) in Pursat. Respondents were asked to name an appropriate price for the filter; the mean non-zero response (n=106) was 9500 riel (2.38 USD): 5900r (1.48 USD) in Kandal, 6700r (1.68 USD) in Kampong Chhnang, and 11800r (2.95 USD) in Pursat.

Among respondents who previously used but are not currently using filters, factors associated with a willingness to purchase an additional filter were using a covered household water storage container (OR: 1.9, 95% CI 1.0-3.3) and having purchased a filter (versus having been given one) before (OR: 3.1, 95% CI 1.6-6.0). When respondents were asked whether household members knew where to purchase additional filters and parts, only 26% did, although distribution points are available in all

three provinces near (<20km from) the intervention locations. Whether these distribution points were readily accessible to respondents was not clear, however.

3.5 Rate of disuse

Time since implementation was calculated from the original implementation questionnaire (delivery) date where possible, followed by estimation based on the date stamped on the filter rim (manufacture date), followed by users' best estimates from interviews. Of the 477 filters for which we were able to get estimates, 253 (53%) were reliably dated using questionnaire or filter data and the remaining were dated by user estimation. Broken filters were often no longer available to inspect. The manufacturing date could not be discerned on many of the oldest filters due to surface wear. Twentynine (29) filters, 6% of the total, could not be dated confidently by any means,.

The major reason for filter disuse was breakage (figure 3.2). Of the 350 disused filters, 328 households provided responses when asked why their filter was out of use at the time of follow up. A total of 214 (65%) were due to filter unit breakage, either of the ceramic filter element, the spigot, or the container. The other one third of respondents gave the following reasons for disuse: the filter is too slow (5%), the filter has passed its recommended use period (5%), gave the filter to a friend or relative (3%), or a number of other reasons. Breakages of the ceramic filter element itself were most common. A number of users reported (and showed evidence of) having repaired the containers or taps on their own using locally-available replacement parts (buckets and taps).

Figure 3.3 presents the distribution of filter time in use for all filters out of use at the time of follow up. These data show extended use periods for many of the filters before disuse: about 2 years on average.

3.6 Factors associated with continued filter use

The most important predictor of the proportion of filters remaining in household use is time since implementation. The results of logistic regression indicate a declining odds of 44% every 6 months of finding a filter still in use (OR: 0.56, 95% CI 0.50-0.63). Figure 3.1 indicates an average rate of disuse of about 2% each month after implementation.

Other important predictors of continued filter use over time controlling for time since implementation were determined to be water source, investment in the technology, access to sanitation, and the practice of other water and hygiene-conscious behaviors in the household. Adjusted odds ratios for measured parameters' associations with continued filter use are presented in table 3.1.

With respect to water source, households who reported groundwater use from deep wells (defined here as >10m) were less likely to use the filter (OR: 0.38, 95% CI 0.18-0.79) after controlling for time since implementation. This is consistent with anecdotal evidence in the study region that suggests low flow rates and rapid clogging of ceramic filters associated with the use of groundwater from deep wells, as a result of insoluble ferric (Fe³+) iron formation from dissolved Fe²+ which occurs in high concentrations in many Cambodian groundwaters. The same association was not observed with households reporting use of shallow wells (OR: 0.91, 95% CI 0.50-1.7), possibly due to Fe oxidation and precipitation that occurs in the water of open wells before water is drawn. Another possible explanation for the difference is that deep wells are perceived to be cleaner and therefore filter use was not seen as critical to protecting water quality. Conversely, a positive association was observed between surface water use and continued filter use (OR: 1.7, 95% CI 1.1-2.7). Similar associations were not observed between continued filter use and the use of covered versus uncovered wells, method of withdrawing water from wells, estimated distance to main drinking water

source, method of withdrawing water from the household water storage container, or use of stored rainwater or bottled water during the study period (the dry season).

Other potentially important demographic predictors of filter use were also examined as a part of the cross sectional study. Sex of household head (OR 1.1, 95% CI 0.63-2.0), number of people in household (OR: 1.0, 95% CI 0.93-1.1), and household wealth index (OR: 0.77, 95% CI 0.50-1.2) were not associated with the outcome of continued filter use after controlling for time since implementation.

Cash investment, at any level, by the household in the filter was associated with continued filter use (OR: 2.1, 95% CI 1.2-3.7) versus receiving the filter *gratis*. Cash payments for the filters ranged from 1000 to 10,000 riel (0.25 – 2.50 USD). No clear trend was observed between filter use and the level of cash investment, however.

Respondents who reported other safe water, sanitation, and hygiene practices were more likely to be using the filter at the time of follow up. For example, access to a household's own or shared latrine (OR: 2.4, 95% CI 1.5-4.0), reporting that all household members always washed hands with soap and water after defecating or before preparing food (OR: 1.6, 95% CI 1.0-2.6), and the presence of soap in the household (OR: 1.7, 1.0-3.0) were all observed to be positively associated with filter use after controlling for time since implementation. The practice of covering the household water storage container may also be positively associated with continued filter use (OR: 1.6, 95% CI 0.94-2.7). No clear association was observed between filter use and respondents reporting on water-related health and hygiene education (OR: 0.74, 95% CI 0.42-1.3),. However observed associations do suggest a relationship between filter use and knowledge of household health and hygiene practices

3.7 Time in use

Of 350 total disused filters, 317 were dated based on original installation records, the lot number and date on the filter rim, or respondents' estimates. Users were asked to approximate, if possible, the date that the family stopped using the filter to the nearest month. Distribution of time-in-use data in 6 month increments is presented in figure 3.1.

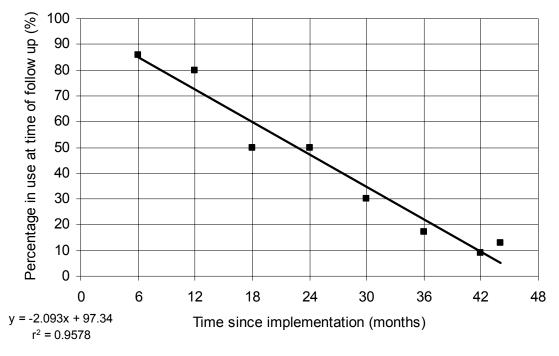


Figure 3.1. Percentage of filters remaining in household use as a function of time, with time as a categorical variable (6 month increments).

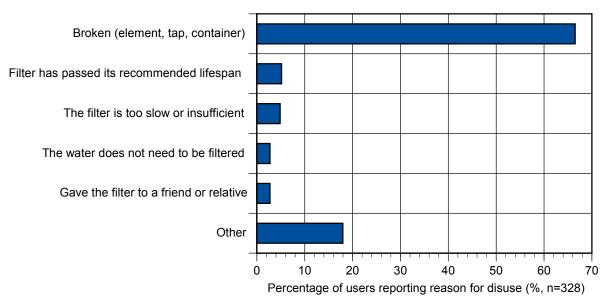


Figure 3.2. Reasons given by respondents for filter disuse at the time of follow up.

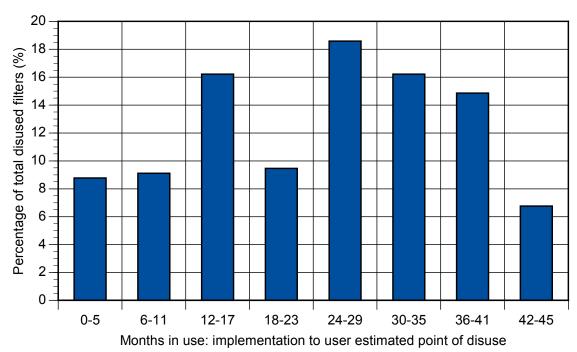


Figure 3.3. Histogram showing the distribution of user-approximated time in use of filters not in use at the time of this follow up study (n=317).

4 RESULTS: LONGITUDINAL STUDY

4.1 Study participants and households

Subjects for the longitudinal water quality and health study were identified and recruited from the cross-sectional study cohort, who in turn were identified from records on the initial implementation of the filters. Eligible and consenting households from the cross-sectional survey were immediately recruited into the longitudinal cohort for further water quality and health data collection. A further 25 households in Kampong Chhnang were recruited from outside the cross-sectional cohort to increase the sample size to 80 total households meeting criteria for intervention households, as required from a priori sample size calculations.

Demographic and other characteristics of the households included in the longitudinal study are presented in table 4.1, by study group. One hundred fifty (159) households completed both follow up visits, with a total of 1007 people (mean household size: 6.3, median age: 18, range: 1-84 years at the time of first household visit. Because having a child ≤5 years of age was a longitudinal study inclusion criterion for households. the age distribution in the two household groups (intervention and non-intervention) may not be representative of the source population in the study villages. One intervention household (1%) was lost to follow up. All households were located in Kandal, Kampong Chhnang, and Pursat provinces in villages where the initial CWP implementations took place.

4.2 Data stratified by study group

The intervention group, those using CWPs regularly, contained 79 households and 528 individuals (6.68 people per household, 53% female, 15% under the age of five). Of these households, 40 (51%) were located in Kandal, 18 (23%) in Kampong Chhnang, and 21 (27%) in Pursat. Respondents were asked more detailed questions about socioeconomic factors (including a direct estimate of household income) and education for the primary caregiver in the household. Reported total household income in 13 (16% of) households was <\$50, in 41 (52% of) households \$50-\$99, in 15 (19% of) households \$100-\$149, and in the remaining 10 households (12%) \$≥150. Education levels for the primary caregiver (usually an adult female) in the intervention group were reported as: 19 (24%) had some or all primary school, 59 (75%) had some or all secondary school, and 1 (1%) had post-secondary training.

The control group (without filters) contained 80 households and 479 individuals (5.98 people per household, 51% female, 18% under the age of five). Of these 80 households, 40 (50%) were located in Kandal, 20 (25%) in Kampong Chhnang, and 20 (25%) in Pursat. Respondents were asked more detailed questions about socioeconomic factors (including a direct estimate of household income) and education for the primary caregiver in the household. Of the 80 control households, 19 (24%) reported total household monthly income as <50, 39 (49%) reported in the \$50-\$99 range, 18 (22%) in the \$100-\$149 range, and the remaining 4 households (5%) \ge \$150. Education levels for the primary caregiver (usually an adult female) in the control group were reported as: 27 (34%) had some or all primary school, 52 (65%) had some or all secondary school, and 1 (1%) had post-secondary training.

4.3 Water use and handling practices

Intervention households not included in the cross-sectional study (from Kampong Chhnang) were asked about water use and handling practices, hygiene and sanitation, and potentially important covariates as in the cross-sectional study. Results are presented in table 4.1. During the study period of February – April (dry season), 43

households (54%) reported using surface water (lake, pond, river, stream, *prek*, *boeng*, or canal) as a primary source of drinking water; 13 (16%) reported use of a deep well (defined here as >10m in depth); 19 (24%) used a shallow well; and 6 (8%) used stored rainwater from the previous rainy season. 23 (29%) used one or more uncovered water storage containers. Respondents were asked to demonstrate to the interviewer the usual method of collecting water from the container for drinking; 35 (44%) of respondents dipped hands or a cup directly into the container, while 44 (56%) used a tap or a dipper which was then poured out into a cup for drinking.

Control households were asked about water use and handling practices, hygiene and sanitation, and potentially important covariates as in the cross-sectional study. Results are presented in table 4.1. During the study period of February – April (dry season), 48 households (60%) reported using surface water (lake, pond, river, stream, prek, boeng, or canal) as a primary source of drinking water; 12 (15%) reported use of a deep well (>10m in depth); 22 (28%) used a shallow well; and 2 (3%) used stored rainwater from the previous rainy season. Thirty (30) (37%) used one or more uncovered water storage containers. Respondents were asked to demonstrate the usual method of collecting water from the container for drinking; 30 (38%) of respondents dipped hands or a cup directly into the container, while 50 (62%) used a tap or a dipper which was then poured out into a cup for drinking.

4.4 Sanitation and hygiene practices

Of the 79 households in the intervention group, 44 (56%) had access to sanitation (either the household's own or a shared latrine). None of the households were connected to a conventional sewerage system. Respondents were asked whether and how often they and members of their family washed their hands, for example after defecating and before preparing food. Of the 79 households, 33 (42%) of respondents indicated that hand washing was practiced by all members of the household "always" at critical points with soap and water. Respondents were also asked to demonstrate that there was soap in the household at the time of the visit; 62 intervention households (77%) were able to produce it.

Of the 80 households in the control group, 35 (44%) had access to sanitation (either the household's own or a shared latrine). None of the households were connected to a conventional sewerage system. Respondents were also asked whether and how often they and members of their family washed their hands, for example after defecating and before preparing food. Of 80 household respondents, 29 (36%) indicated that hand washing was practiced by all members of the household "always" at critical points with soap and water. Respondents were also asked to demonstrate that there was soap in the household at the time of the visit; 70 control households (87%) were able to produce it.

Characteristic	Intervention group (79 households*)	Control group (80 households)
Number (percent) of households by province	(73 Households)	(00 Households)
Kandal	40 (51%)	40 (50%)
Kampong Chhnang	18 (23%)	20 (25%)
Pursat	21 (27%)	20 (25%)
Total number of people in group	528	479
Mean number of individuals per household	6.68	5.98
Number (percent) female	280 (53%)	243 (51%)
Number (percent) refilide Number (percent) children < 5 years of age	77 (15%)	86 (18%)
Number (percent) children 5-15 years of age	143 (27%)	148 (31%)
Soap observed in household ^a	143 (21 /0)	140 (3170)
Yes	62 (770/)	70 (87%)
No	62 (77%) 18 (23%)	10 (13%)
Reported total household income (USD/month)	10 (23 /0)	10 (1370)
<\$50	12 (160/)	10 (240/)
\$50-\$99	13 (16%)	19 (24%)
\$100-\$149	41 (52%) 15 (19%)	39 (49%) 18 (22%)
\$150-\$149 \$150-\$200	,	` ,
\$130-\$200 >\$200	9 (11%)	4 (5%)
	1 (1%)	0 (0%)
Access to sanitation ^b	44 (EGO/)	25 (440/)
Yes	44 (56%)	35 (44%)
No	35 (44%)	45 (56%)
Reported receiving health education ^c	22 (200/)	60 (750/)
Yes No	23 (29%)	60 (75%)
	56 (71%)	30 (25%)
Covered water storage container	EC (740/)	E0 (C20/)
Yes No	56 (71%)	50 (63%)
	23 (29%)	30 (37%)
Wash hands with soap? ^d	22 (420/)	20 (260/)
Yes	33 (42%)	29 (36%)
No	46 (58%)	51 (64%)
Main drinking water sources during study (dry season) ^e	42 (E40/)	49 (600/)
Surface water	43 (54%)	48 (60%)
Groundwater	12 (160/)	10 (150/)
Deep well (>10m) Shallow well	13 (16%)	12 (15%)
	19 (24%)	22 (28%)
Rainwater Observed method of drawing water	6 (8%)	2 (3%)
Observed method of drawing water [†]	25 (440/)	20 (200/)
Use hands	35 (44%)	30 (38%)
Pour or tap	44 (56%)	50 (62%)
Formal education level of primary caregiver ^g	10 (240/)	27 (240/)
Some or all primary school	19 (24%)	27 (34%)
Some or all secondary school	59 (75%)	52 (65%)
More than secondary *One intervention households was lost to follow up	1 (1%)	1 (1%)

^{*}One intervention households was lost to follow up.

Table 4.1. Characteristics of the intervention (households with CWPs) and control (without CWPs) groups.

a. Respondents were asked to demonstrate that soap was present in the household.

b. Shared or own latrine.

c. Water, health, hygiene, or sanitation education from any source (school, NGO, media, etc).

d. Users who responded that they did wash hands "always" with soap at critical points such as after defecating.

e. Multiple answers possible.

f. Respondents were asked to demonstrate their usual method of gathering water from the storage container.

g. Usually an adult female who is responsible for child care.

4.5 Water quality data

World Health Organization risk categories for drinking water (WHO 2003) according to *E. coli* are: 0 *E. coli*/100ml (compliance), 1-10 *E. coli*/100ml (low risk), 11-100 *E. coli*/100ml (intermediate risk), 101-1000 *E. coli*/100ml (high risk). Household drinking water quality (intervention and control households) data are presented in table 4.2. Filters were able to supply high quality (low risk) drinking water to users: 66% of filter effluent samples were under 10 *E. coli*/100ml, with 40% of samples having 0 *E. coli* detected in 100ml samples. Seventy-three percent (62%) of household drinking water samples from control households were considered "high risk" (≥101 cfu/100ml *E. coli*) versus 14% of samples from intervention households (table 3). A summary of means of total coliform, *E. coli*, and turbidity counts in intervention household samples (both treated and untreated water) is presented in table 4.3. The mean *E. coli* concentration in filtertreated water was 163 cfu/100ml (95% CI 61.44-264.2) against 3002 cfu/100ml (95% CI 2008-3996) in control households.

Filter effluent samples are not necessarily indicative of actual filter performance, however. This is because untreated water may already be of high quality, or because the indicator concentration in untreated water is so high that the filter could perform admirably well and still retain detectable indicator levels in samples of treated water. Performance is generally gauged through the calculation of log₁₀ reduction values (LRVs).

4.5.1 Loq₁₀ reduction values (LRVs)

The \log_{10} reduction values of *E. coli* in treated versus untreated water are presented as standard measures of technology performance. Based on 203 total samples over three sampling rounds, the mean \log_{10} reduction of *E. coli* using the CWP was 1.3 (95% CI 1.10-1.51, n=203) or 95.1%. The mean \log_{10} reduction of total coliforms using the CWP was 1.0 (95% CI 0.82-1.22, n=203) or 90%. The mean reduction in turbidity was 73% (95% CI 68%-78%, n=203).

LRVs may also be misleading when improperly interpreted. For many of the filter effluent samples where there were no detectable E. coli in 100ml samples, the calculated LRV may be underestimating performance, because the LRV is a function of the influent concentration and the effluent concentration. A non-detect value in the filtered water does not allow a determinate value to be calculated for the ability of the filter to reduce the indicator. For this reason, many of the LRV values presented should be considered minima. The filters were not sampled under challenge conditions meant to test the maximum extent of microbiological effectiveness. Furthermore, the actual reductions of E. coli by the filter could be underestimated because E. coli remaining in the filtrate could increase in numbers in the water during storage. The water storage vessel of the CWP is intended to minimize post-filtration contamination by having a spigot to dispense water and providing no easy access to the interior of the container for hands or dipping devices (cups, ladles, etc.). However, it is commonly observed that post-filtration contamination of water occurs during storage due to bacterial growth. The extent to which such E. coli growth could have occurred in the stored water of control and filter households was not determined and is unknown.

	Number (percentage ^a) of all samples by <i>E. coli</i> concentration of household drinking water ^b						
	0	1-10	11-100	101-1000	1,001+	Total	
	(cfu/100ml)	(cfu/100ml)	(cfu/100ml)	(cfu/100ml)	(cfu/100ml)	samples ^c	
Control	40 (18%)	2 (1%)	42 (19%)	80 (35%)	62 (27%)	226	
households							
Kandal	15 (13%)	2 (2%)	24 (21%)	46 (39%)	30 (26%)	117	
Kampong Chhnang	13 (24%)	0	7 (13%)	15 (28%)	19 (35%)	54	
Pursat	12 (22%)	0	11 (20%)	19 (35%)	13 (24%)	55	
Intervention households	89 (40%)	54 (26%)	38 (18%)	23 (11%)	7 (3%)	211	
Kandal	53 (47%)	32 (29%)	17 (15%)	9 (8%)	1 (1%)	112	
Kampong Chhnang	18 (42%)	12 (28%)	6 (14%)	4 (9%)	3 (7%)	43	
Pursat	18 (32%)	10 (18%)	15 (27%)	10 (18%)	3 (5%)	56	

Table 4.2. Observed levels of E. coli (cfu/100ml) in household drinking water by study group.

<sup>a. Percentages within strata may not add up to 100% due to rounding.
b. Samples were filter effluent in intervention households, stored household drinking water for control households. Households were asked to provide a sample of the water that the family was drinking at the time of</sup>

c. Incomplete data for 14 (6%) control households and 29 (12%) intervention household samples.

	Water quality data ^a , means (untreated water)			Wate	er quality data ^a , (treated water	
		E.coli/100ml	Turbidity (NTU)	TC/100ml	E.coli/100ml	Turbidity (NTU)
All provinces	13,861	2264	8.70	1957	163	1.53
Kandal	10,264 22,467	1112 3338	2.71 4.10	1152 2793	77 305	0.78 1.65
Kampong	,					
Chhnang Pursat	14,229	3658	24.3	2944	225	3.25

a. Data from intervention households, raw (untreated) water and filtered (treated water) samples from 3 sampling rounds, February-April 2006.

Table 4.3. Mean total coliform and *E. coli* counts (cfu/100ml) and turbidity averages for samples taken in intervention households (untreated and treated water).

	Percenta (n=203°)	ige ^a of all	filter sample	s by <i>E. coli</i>	i, log ₁₀ redu	ction value	s ^b (LRV)
	<0 _q	0 ^e	.01-0.99	1-1.99	2-2.99	3-3.99	4.0+
All provinces	17%	10%	12%	16%	36%	7%	2%
Kandal	16%	12%	7%	20%	43%	5%	3%
Kampong Chhnang	19%	10%	12%	7%	40%	10%	2%
Pursat	19%	6%	23%	17%	17%	25%	11%

a. Percentages may not add to 100% due to rounding.

Table 4.4. Summary of log₁₀ reduction values of *E. coli* by CWPs, by province.

4.5.2 Negative log₁₀ reduction values

Treated water concentrations greater than untreated water concentrations for the indicator under study (*E. coli*, cfu/100ml) lead to negative log₁₀ reduction values (LRVs). Out of 79 filters in the intervention group, 46 were observed to have negative LRVs at one or more visits: 20 (50%) filters in Kandal, 10 (56%) in Kampong Chhnang, and 10 (48%) in Pursat. Nine filters (11%) failed at multiple time points. This result could be explained in several ways, but for this system two explanations are most likely.

The first is variation in the indicator's concentration in the raw water over time. That is, when filter effluent is sampled, the filtered water sample is by no means "the same" as the water in the household storage container or even perhaps as the water in the filter element above. Since *E. coli* concentrations are known to vary greatly over time, a simple comparison between the untreated and treated water will not always be a

b. Log₁₀ reduction values are computed as the log₁₀(effluent/influent); 1 LRV=90% reduction, 2 LRV=99% reduction, 3 LRV=99.9% reduction, and so on. Reduction is a function of influent water, however, and low LRV values do not necessarily indicate poor performance. In many cases, filters reduced product water to 0 *E. coli* per 100ml; here the calculated LRV potentially underestimates performance.

c. Only 203 (85%) sampling events (out of 240 total: 80 filters sampled three times each) yielded complete data to use in the LRV calculation.

d. Negative LRV values indicate that the effluent water contains more *E. coli* than the influent water.

e. In 100% of these samples the influent water contained 0 E. coli/100ml.

valid measure of difference attributable to the performance of the filter. Negative LRVs may be observed when the concentration of *E. coli* in water being put through the filter has substantially declined over the duration of the filter run (which could be hours). Water in the top of the filter may also be from a different, less contaminated source, or from the same source storage container that has been exposed to microbe-inactivating sunlight, to sedimentation (settling out of bacteria associated with larger particles in the water) or some other factor influencing the presence or culturability of the indicator sought in the water sample.

The second explanation for negative LRVs is filter recontamination during use, for example due to improper cleaning or handling. While the storage system used with the ceramic water filters is generally thought to be safe (closed storage container, water dispensed via a tap), contamination of the filter could be introduced through frequent cleaning or cleaning with a contaminated cloth. As indicated previously, E. coli in filtered water could also multiply during storage. Seventy-seven (77%) percent of households in the intervention group reported cleaning the filter element with a cloth or krama (n=79) and 71% reported cleaning the storage container with a cloth or krama (n=79). Eightynine percent (89%) of users reported cleaning the filter and 29% reported cleaning the storage container with raw water only, with the remainder using soap and raw water. The mean reported frequency of cleaning the filter was 2.3 times per week. Kramas are multi-use traditional cloths used around the household in Cambodia, which are thought to be important vectors for germs. Cleaning the filters with these cloths may be one means of compromising the filter and recontaminating the stored water. No clear associations were observed, however, between the probability of negative LRVs (achieving <0 log₁₀ reduction of *E. coli*) and measured parameters such as reported frequency of use, frequency of cleaning, method of cleaning the filter or bucket, number of people in the household, manufacturer, time in use, or other factors as determined by logistic regression.

4.5.3 Stored boiled water

Many households reported using boiled water for some or all of the household drinking water (55% of control households, 33% of intervention households), although in practice this water is often reserved for adults only. In order to compare stored, treated water quality between the CWP and stored, boiled water, a total of 84 boiled water samples were taken and processed for *E. coli*, total coliforms, turbidity, and pH along with other water samples. The log₁₀ reduction value distribution for the two treatment methods are similar, including the percentage of samples having worse quality than the untreated (raw) water stored in the home as determined by *E. coli* counts (table 4.5). These results suggest that, although these methods for treating water are effective, there is serious risk of recontamination of water through unsafe handling practices. Education and training in safe storage practices should be part of any effective program to improve water quality in the home. These results are consistent with several studies (e.g., Wright et al. 2004 and Jensen et al. 2002) showing that recontamination of stored water in the home could significantly impact the quality of potable water used in the household.

The mean \log_{10} reduction of *E. coli* using the CWP was 1.3 (95% CI 1.10-1.51, n=203), or 95.1%, versus 1.7 for boiling (95% CI 1.45-2.01, n=84) or 98.2%. The mean turbidity in stored, boiled water samples was 8.6, versus 1.5 for samples taken from CWPs. Excluding filter samples where the \log_{10} reduction was less than 0, the mean \log_{10} reduction value of *E. coli* in the CWPs was 1.78 (95% CI 1.62-1.95) or 98.4%.

	Comparison of percentage ^a of filter effluent samples versus stored <i>boiled</i> water samples ^b (control households) by <i>E. coli</i> , log ₁₀ reduction values ^c (LRV)								
	<0 ^d	0 ^e	.01-0.99	1-1.99	2-2.99	3-3.99	4.0+		
CWP	17%	10%	12%	16%	36%	7%	2%		
Stored boiled water	13%	7%	5%	21%	40%	11%	2%		

a. Percentages may not add to 100% due to rounding.

Table 4.5. Summary of distribution of log_{10} reduction values of *E. coli* by CWPs compared with boiled, stored water.

b. 203 total samples from CWPs, 84 from stored boiled water.

c. Log_{10} reduction values are computed as the log_{10} (effluent/influent); 1 LRV=90% reduction, 2 LRV=99% reduction, 3 LRV=99.9% reduction, and so on. Reduction is a function of influent water, however, and low LRV values do not necessarily indicate poor performance. In many cases, filters reduced product water to 0 *E. coli* per 100ml; here the calculated LRV potentially underestimates performance.

d. Negative LRV values indicate that the effluent water contains more *E. coli* than the influent water.

e. In 100% of these samples the untreated water contained 0 E. coli/100ml.

4.5.4 Filter effectiveness and time

There did not appear to be a strong correlation between filter effectiveness and time in use (tables 4.6 and 4.7, figures 4.3 and 4.3). Microbiological effectiveness as indicated by *E. coli* LRVs or by *E. coli* quantification of filter effluent revealed no trend over samples taken from filters representing a broad range of time in use.

Number (percentage ^a) of filter samples by <i>E. coli</i> , log ₁₀ reduction values										
	(LRV) (n=203°), stratified by time since implementation									
Time since	<0 ^d	0 ^e	.01-0.99	1-1.99	2-2.99	3-3.99	4.0+			
implementation										
(months)										
All (0-48)	35	20	24	32	73	15	4			
0-5	8 (23%)	6 (30%)	2 (8%)	4 (13%)	18 (25%)	4 (27%)	1 (25%)			
6-11	4 (11%)	1 (5%)	2 (8%)	7 (22%)	7 (10%)	0	0			
12-17	0	2 (10%)	1 (4%)	4 (13%)	5 (7%)	0	0			
18-23	8 (23%)	5 (25%)	2 (8%)	5 (16%)	14 (19%)	1 (7%)	2 (50%)			
24-29	1 (3%)	1 (5%)	3 (13%)	5 (16%)	2 (3%)	1 (7%)	0			
30-35	1 (3%)	O	2 (8%)	Ò	4 (5%)	1 (7%)	0			
36-41	5 (14%)	2 (10%)	6 (25%)	4 (13%)	14 (19%)	7 (47%)	1 (25%)			
42-48	8 (23%)	3 (15%)	6 (25%)	3 (9%)	9 (12%)	1 (7%)	0			

a. Percentages may not add to 100% due to rounding.

Table 4.6. Summary of log₁₀ reduction values of *E. coli* by CWPs, by time in use.

Number (percentage ^a) of filter-treated water samples by <i>E. coli</i> concentration, stratified by time since implementation							
Time since	0	1-10	11-100	101-1000	1,000+	Total	
implementation	(cfu/100ml)	(cfu/100ml)	(cfu/100ml)	(cfu/100ml)	(cfu/100ml)	samples ^b	
(months)							
All (0-48)	89	54	38	23	7	211	
0-5	22 (25%)	13 (24%)	4 (11%)	4 (17%)	1 (14%)	44	
6-11	11 (12%)	5 (9%)	3 (8%)	3 (13%)	0	22	
12-17	6 (7%)	2 (4%)	4 (11%)	0	0	12	
18-23	16 (18%)	12 (22%)	8 (21%)	3 (13%)	0	39	
24-29	4 (5%)	4 (7%)	4 (10%)	2 (9%)	0	14	
30-35	4 (5%)	1 (2%)	1 (3%)	2 (9%)	0	8	
36-41	15 (17%)	11 (20%)	8 (21%)	5 (22%)	1 (14%)	40	
42-48	11 (12%)	6 (11%)	6 (16%)	4 (17%)	5 (71%)	32	

a. Percentages within strata may not add up to 100% due to rounding.

Table 4.7. Summary of *E. coli* counts (cfu/100ml) in filter treated water, by time in use.

b. Log₁₀ reduction values are computed as the log₁₀(effluent/influent); 1 LRV=90% reduction, 2 LRV=99% reduction, 3 LRV=99.9% reduction, and so on. Reduction is a function of influent water, however, and low LRV values do not necessarily indicate poor performance. In many cases, filters reduced product water to 0 *E. coli* per 100ml; here the calculated LRV potentially underestimates performance.

c. Only 203 (85%) sampling events (out of 240 total: 80 filters sampled three times each) yielded complete data to use in the LRV calculation.

d. Negative LRV values indicate that the effluent water contains more *E. coli* than the influent water.

e. In 100% of these samples the influent water contained 0 E. coli/100ml.

b. Incomplete data for 29 (12%) samples.

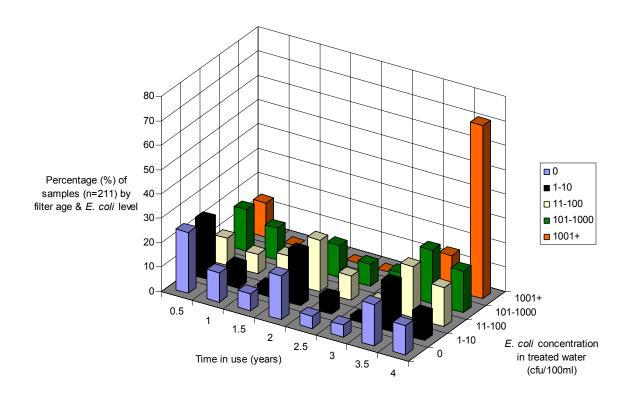


Figure 4.2. Filter E. coli (cfu/100ml) effluent concentrations by time in use (table 4.7).

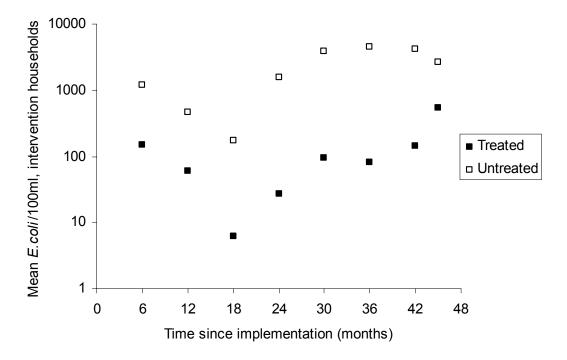


Figure 4.3. Mean *E. colil* 100ml counts in filter effluent, including filters with a negative LRV, by time since implementation (note log scale).

4.6 Diarrheal disease

A clear negative association in diarrheal disease prevalence was observed in filter households (intervention) households compared to control (non-filter) households, in all age groups, both sexes, and in each province (table 4.8), indicating a strong protective effect of the intervention. The adjusted risk ratio (RR) effect estimate for all ages was 0.54 (95% CI: 0.41-0.71), corresponding to a reduction in diarrheal disease of 46%. The estimates were adjusted for no covariates as none produced a ≥10% change-in-estimate of effect. A greater estimate of effect was observed where the background (control) prevalence proportion of individuals reporting diarrhea was higher. The age group of 5-15 year olds exhibited a statistically significant lower mean prevalence in the control group, producing a higher adjusted risk ratio.

	Mean diarrheal dis over 2.5 month stu	•	Adjusted risk ratio (RR) ^b	95% CI ^c
	Intervention	Control		
Age ^d				
All ages	0.10	0.18	0.54	0.41-0.71
<5 years	0.19	0.37	0.52	0.32-0.86
5-15 years	0.07	0.10	0.72	0.39-1.3
≥16 years	0.09	0.16	0.52	0.35-0.76
Sex				
Male	0.10	0.19	0.51	0.34-0.75
Female	0.10	0.17	0.57	0.38-0.84
Province				
Kandal	0.08	0.13	0.63	0.41-0.97
Kampong	0.12	0.18	0.70	0.42-1.2
Chhnang				
Pursat	0.10	0.27	0.37	0.22-0.62

a. Two sampling rounds, February-April 2006 (dry season). Figures represent the proportion of individuals reporting diarrhea in the previous 7 days.

Table 4.8. Diarrheal disease prevalence and filter effect estimates by age and sex of individuals and province.

Diarrheal disease (7 day recall) was also examined as an outcome with water quality (*E. coli* cfu/100ml) as the exposure variable. There was observed to be a positive association between reported diarrhea and increasing levels of *E. coli*, although this association was not strong nor did the effect increase linearly with concentration. Results of log-risk regression are presented in table 4.9.

The water quality parameters used in this study are known to vary by season and diurnally, so water quality data may not represent the average drinking water quality in use by the household. At best, these data represent a series of point estimates of *E. coli* in water across the community that can perhaps approximate levels of waterborne pathogen concentrations across space and time. For this reason, making clear associations between water quality data based on *E. coli* levels and the outcome of diarrheal illness may be tenuous at best. Other recent studies have failed to explicitly observe this association. The recent meta-analysis by Gundry et al. (2004) concluded that there was no clear association between levels of indicator bacteria (*E. coli*, thermotolerant coliforms) and diarrhea in a systematic review of intervention trials.

b. Adjusted for clustering of diarrheal disease within households and within individuals over time.

c. 95% confidence interval.

d. Age in years at the time of the first household visit.

Similarly, Moe et al. (1991) found no relationship between diarrheal illness rates and good quality (<1 *E. coli*/100ml) versus moderately contaminated water (2-100 *E. coli*/100ml) in a field study from the Philippines.

Possible explanations for these results are that (i), E. coli is not a sufficiently good indicator of waterborne diarrheal disease in the context of this study (dry season. stored household drinking water in rural Cambodia); (ii), that measured health impact data (diarrheal disease occurrence) are misleading due to a placebo effect of the filters (e.g., Hellard et al. 2001; Colford et al. 2002) and/or that drinking water may not be an important route of exposure to diarrheogenic pathogens in the population at the time of the study; (iii), that health data are biased due to recall (Boerma et al. 1991) or reporting issues (Thomas and Neumann 1992); or that (iv), the measured E. coli concentration from the time of sampling is not representative of the drinking water quality consumed by all the household members during the previous 7 days. The last point of representativeness of single water samples for 7 days of drinking water quality is particularly important, as water quality could vary greatly on a daily basis. Despite these factors tending to obscure the relationship between the fecal bacterial indicator E. coli and reported diarrheal disease, a positive association was observed at higher levels of E. coli cfu/100ml (table 4.9).

E. coli/100ml in household drinking water ^a	Stratum-specific risk estimate	Risk ratio (RR) ^b	95% CI
0	0.12	1.0 (referent)	
1-10	0.10	0.82	0.77-0.87
11-100	0.17	1.40	1.30-1.50
101-1000	0.16	1.26	1.18-1.36
1001+	0.14	1.14	1.04-1.09

a. Samples were filter effluent in intervention households, stored household drinking water for control households. Households were asked to provide a sample of the water that the family was drinking at the time of visit. In control households, samples were taken of the stored water only if the household reported use of boiled water by some, but not all, household members.

b. Adjusted for clustering within households.

Table 4.9. Stratum-specific risk estimates for levels of *E. coli* in household drinking water samples.

4.7 Willingness to pay

Users' willingness to pay for replacement filters was assessed using contingent valuation (CV) methods. Respondents (all current filter users) were asked a closed (yes or no) question type about willingness to pay increasing amounts of \$2.50, \$4, and \$5 (USD) for a ceramic filter replacement element, if the household needed one. Of the 79 intervention households, 72% of respondents were willing to pay \$2.50, 29% were willing to pay \$4, and 26% were willing to pay \$5 (figure 4.3). When respondents were asked to estimate a price at which most people could afford to purchase a filter, the mean reported price for filters was 7,294 riel (approximately \$1.87). The cost of replacement ceramic filter elements Cambodia is in \$2.50-\$4 in the range.

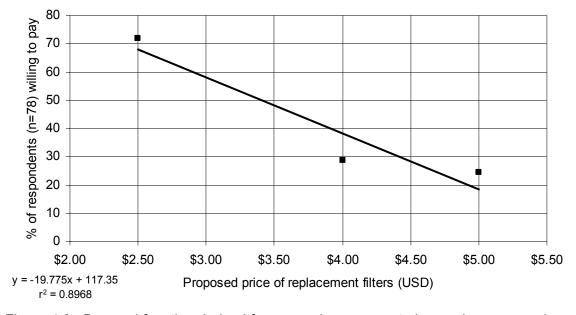


Figure 4.3. Demand function derived from users' responses to increasing proposed prices for filter replacements.

5 DISCUSSION: CROSS-SECTIONAL STUDY

Results suggest that ceramic water filters are more likely to be used by households who (i) already have some knowledge of safe water, sanitation, and hygiene practices; (ii) invest in (purchase) the technology; (iii) use surface water sources for drinking water; and (iv), who do not use deep wells (>10m) as a primary source of drinking water. The high rate of breakage of the filters suggests that the availability of replacement parts and access to distribution points may limit the sustainability of ceramic filter intervention efforts. This is because a predicted 2% of filters may fall into disuse each month after implementation due to breakage. It is recognized, however, that NGO filter (hardware) models and implementation strategies are improving and this study accounts only for those in use previously. Despite the declining use rate, user satisfaction with the filters was generally very high, and a high percentage of users reported a willingness to purchase additional filters. Time in use for filters in households was about 2 years, on average, before disuse (figure 3.3). This suggests that filters can be used reliably for extended periods and also that users valued the filters enough to keep using them, usually until breakage. Greater availability and accessibility of spare parts, especially the ceramic filter elements themselves, should enhance the sustainability of the intervention.

The declining use rate of 2% per month is consistent with the findings of one other ceramic filter implementation study that reported a decline in use of approximately 20% after 9 months in Bolivia in the absence of replacement filters (Clasen et al. 2006). No other reliable estimates of household water treatment uptake and use rates over time have been published in the peer-reviewed literature, but there is some evidence that this is a major factor limiting the success of household water treatment, for all technologies. For example, PUR, a disinfectant/coagulant chemical treatment product, saw repurchase (uptake) proportions of 5-13% in test markets in Guatemala, The Philippines, and Pakistan (Allgood 2005), although it is not clear over what time span these rates were observed. Unpublished data on a solar water disinfection method using PET bottles from Bolivia indicated that household use of the method had fallen to 25% within the first year.

6 DISCUSSION: LONGITUDINAL STUDY

Use of a CWP was associated with a substantial improvement in drinking water quality at the household level compared a matched control group not using filters. Use of the filters was also associated with a reduced diarrheal disease burden, with diarrhea prevalence during the study being only 54% in filter households of that in the control (non-filter) households. There does not appear to be a change in the relationship between filter effectiveness and time, supporting the hypothesis that the filters can maintain effectiveness for up to 4 years (and potentially longer) in household use. The filters are susceptible to re-contamination, however, as are all household water treatment methods, including the most effective method (boiling), as was observed in this study. While improving the technology is important, it must also be stressed that proper use of the technology is as critical as the technology itself. Behavioral change and education "software" accompanying interventions may increase proper use of the filters and result in lower levels of recontamination and possibly lower risks of waterborne diarrheal disease.

There was a positive association observed between bacterial indicator levels and reported diarrheal disease, although the relationship was not strong or highly predicted by *E. coli* levels in the water. This lack of strong predictability of *E. coli* levels for diarrhea risks could be due to the inability of *E. coli* to reliably predict diarrheaogenic pathogen levels in the water, changes in *E. coli* levels in water during storage or other factors we were unable to account for in this study. The lack of predictability of waterborne diarrhea risks by levels of fecal indicator bacteria such as *E. coli* has been previously reported.

Seasonal effects on diarrheal disease prevalence or microbiological water quality were not accounted for in this study, conducted entirely in the dry season. Annual rainfall is not evenly distributed throughout the year in Cambodia: during the rainy season (June - October) it rains between 15 and 30 cm per month, with dry season (December - March) averages of 0-5 cm per month. Water use practices, water treatment practices, diarrheal disease rates, and the presence of microbial pathogens and indicators in potential drinking water sources can vary greatly depending upon the season (Gleeson and Gray 1997). In many tropical developing countries, diarrheal disease prevalence tends to peak during or after the rainy season. The opposite may also be true in some countries where the dry season entails a shift away from the use of relatively safe rainwater to relatively unsafe surface water sources, or where water scarcity in the dry season is associated with decreased hygiene practices or their greater Longitudinal studies, such as this one, that attempt to capture the ineffectiveness. protective effect of an intervention on diarrheal disease are subject to possible effect measure modification by seasonal effects, resulting in very different quantitative findings or even outcomes over the course of a year as conditions change.

7 SUMMARY AND RECOMMENDATIONS

Major findings are that (i), the rate of filter disuse was approximately 2% per month after implementation, due largely to breakages; (ii), controlling for time since implementation, continued filter use over time was most closely positively associated with related water, sanitation, and hygiene practices in the home, cash investment in the technology by the household, and use of surface water as a primary drinking water source; (iii), the filters reduced *E. colil* 100ml counts by a mean 95.1% in treated versus untreated household water, although demonstrated filter field performance in some cases exceeded 99.99%; (iv), microbiological effectiveness of the filters was not observed to be closely related to time in use; (v), the filters can be highly effective against microbial indicator organisms but may be subject to recontamination, probably during regular cleaning; and (vi), the filters were associated with an estimated 46% reduction in diarrhea in filter users versus non users (RR: 0.54, 95% CI 0.41-0.71).

The ceramic water purifier, as a public health intervention, holds much promise for Cambodia and her millions without access to safe water. The filter's demonstrated effectiveness in improving water quality and health, over a wide range of conditions, makes it among the best available options for household water treatment. Results suggest more work is needed, however, in order to ensure the intervention's continued effectiveness and sustained use. Education and behavioral change software must accompany efforts to implement the filters, as recontamination through improper use is a major risk and potential barrier to effectiveness. Also, availability and accessibility of spare parts, particularly replacement ceramic filter elements, will greatly enhance the sustainability of this intervention. It is also recommended that filters be sold to users, rather than given away, as user investment is related to sustained use. Preliminary work on user willingness to pay suggests that demand exists and full or partial cost recovery is possible.

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