

Sustained use of a household-scale water filtration device in rural Cambodia

Joe Brown, S. Proum and M. D. Sobsey

ABSTRACT

The effectiveness of point-of-use water treatment may be limited by declining use over time, particularly when water treatment is introduced via targeted intervention programmes. In order to evaluate the long-term uptake and use of locally produced ceramic water filters in rural Cambodia, we visited households that had received filters as part of NGO-subsidized distribution programmes over a 4 year period from 2002 to 2006. Of the more than 2,000 filters distributed, we visited 506 randomly selected households in 13 villages spanning three provinces to assess filter time in use and to collect data on factors potentially correlated with long-term use. Results indicate that filter use declined at the rate of approximately 2% per month after implementation, largely owing to breakages, and that, 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.

Key words | Cambodia, point-of-use, sustainability, water quality

Joe Brown (corresponding author)
Department of Biological Sciences,
New College, University of Alabama,
Box 870229 Carmichael Hall,
Tuscaloosa AL 35487-0229,
USA
E-mail: joebrown@as.ua.edu

S. Proum
Department of Chemistry,
Royal University of Phnom Penh,
Phnom Penh,
Cambodia

M. D. Sobsey
Department of Environmental Sciences and
Engineering,
University of North Carolina School of Public
Health,
CB 7431 Rosenau Hall,
Chapel Hill, NC 27599-7431,
USA

INTRODUCTION

Point-of-use or household-based water treatment is increasingly promoted as a promising strategy to increase global access to safe drinking water (Sobsey 2002). While point-of-use water treatment interventions are becoming more widespread and supported by a growing number of studies, there is a general lack of information on intervention sustainability after initial implementation efforts. If point-of-use water treatment is to be taken seriously as a viable option for the long-term provision of safe drinking water, interventions must continue to be used successfully over extended periods after implementing organizations have stopped watching.

One emerging point-of-use water treatment technology is the ceramic water purifier (CWP), a household-scale, porous ceramic filter adapted locally from the *Potters for Peace* model developed in Central America. Filters of this type are supported by a number of published and unpublished studies indicating microbiological effectiveness

(Lantagne 2001; Duke *et al.* 2006; Mattelet 2006; Van Halem 2006; Oyanedel-Craver & Smith 2008) and impacts on user health (AFA Guatemala 1995; Roberts 2004), including one randomized, controlled trial in Cambodia showing substantial reduction in diarrhoeal disease in users versus non-users (Brown *et al.* 2008). Although an estimated 100,000 CWPs have been distributed in Cambodia since 2002, no data exist on the percentage still in use. This study aims to assess whether and how long filters were used successfully after initial interventions and what factors contributed to their long-term use in households.

METHODS

This study included filters produced by International Development Enterprises (IDE) from 2002 to 2006 and Resource Development International (RDI) from 2003

to 2006. Filters were implemented originally in three provinces of Cambodia (Figure 1). Interventions in Kampong Chhnang and Pursat provinces were carried out by IDE from July 2002. RDI conducted implementation programmes from December 2003 in Kandal province. Each NGO distributed approximately 1,000 filters in these intervention efforts; the amount of education and training given to users, the price charged to households, and other details of the interventions differed between the NGOs and varied over time as approaches were refined and locally adapted. In order to assess factors related to uptake and long-term use of the technology, we measured the continued use of the filters over time as the proportion of filters still in use since introduction. Survey data intended to elucidate factors influencing implementation success and the challenges facing the long-term sustainability of this intervention in Cambodia were also collected.

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 for a total of 600 households in 13 rural villages. Of these, 506 could be located and consented to participate in the survey.

Household visits took place during the months of February and March 2006. After obtaining informed consent from the head of household (and adult female, if a different person), the data collection team first determined whether the filter was in current use. Criteria for 'current use' were that: (i) the filter was in good working order (filter element, tap, and receptacle intact and apparently functional); (ii) it contained water or was damp from recent use; and (iii) one or more household members reported daily use for the production of drinking water. Since filters typically take 3 or more days to dry completely, filters that were dry were not considered in current use. Time in use for each filter was established based on manufacturing date stamped on the filter at the factory, delivery date as recorded by the NGO, or through user interviews.

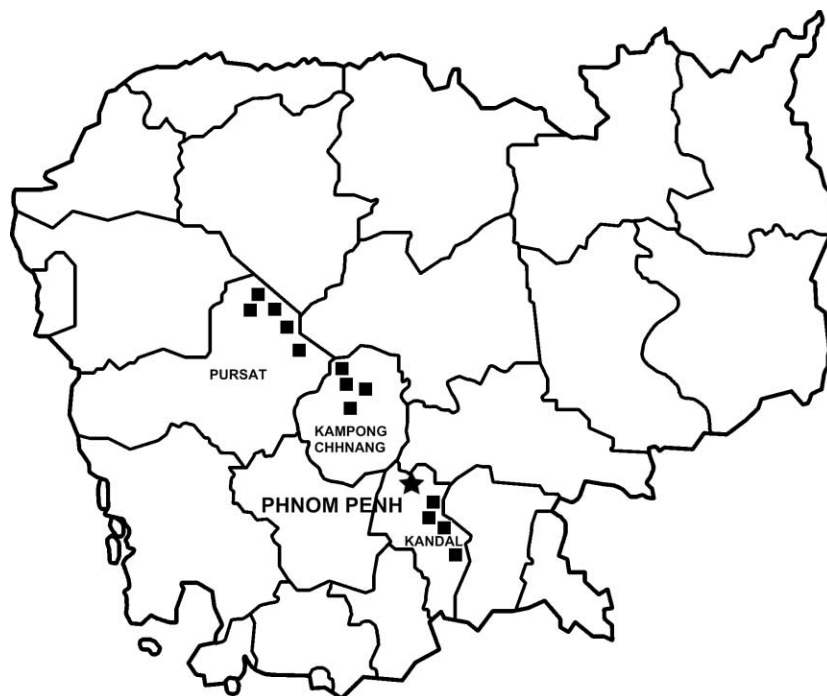


Figure 1 | Map showing locations of provinces and villages included in the study (squares) in Cambodia. Study households were taken from 13 rural villages in the provinces of Kandal, Kampong Chhnang and Pursat, Source: Jan-Willem Rosenboom, WSP-Cambodia.

A questionnaire was administered to the adult female, as the person generally charged with water collection and management for the household. Interviews elicited data on a variety of covariates potentially associated with continued use of the filters under a variety of conditions during up to 44 months of use. Data on basic household demographics, household water handling and use, sanitation, health and hygiene behaviours, and other factors thought to be related to CWP adoption and use were collected. Self-reported income and a wealth index measure, based on access to electricity and an inventory of household possessions indicative of relative wealth, were used to gauge socio-economic status. 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.

All survey instruments were prepared in both English and Khmer before use in the study; they were pre-structured and pre-tested by back-translation from Khmer to English and used in pilot interviews to determine suitability of content and structure, reliability and consistency. The data collection (field) team was composed of four interviewers who were native speakers of Khmer and had experience in community health data collection in the study areas. This project and its means for obtaining informed consent from participants were reviewed and approved by the Biomedical Institutional Review Board, The University of North Carolina at Chapel Hill, USA, and the Ministries of Health and Rural Development, Cambodia.

Survey data were collected via verbally administered questionnaires and recorded onto hard copy data sheets. Survey data were entered into a Microsoft Excel spreadsheet and transferred to Stata (version 8.1) for statistical analysis. All data were entered twice to ensure consistency and accuracy of data input. Logistic regression reporting odds ratios (OR) and 95% confidence intervals (CIs) 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. Confounders were identified by an a priori 10% change in estimate of effect criterion employed in a series of forward selection and backward elimination models.

RESULTS

A total of 506 households with an average of 5.9 people per household were included in the study (total number of persons = 2,965, 52% female). 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. Table 1 presents data summarized over provinces and estimated odds ratios. Odds ratios were calculated based on all households using filters versus those not currently using filters (summarized 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.

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 greatly by location. During the study period of February–March (dry season), 243 households (48%) reported using surface water (lake, pond, river, stream or canal) as a primary drinking water source (PDWS); 79 (16%) reported use of a deep well (defined here as ≥ 10 m in depth); 152 (30%) used a shallow well; 39 (8%) used stored rainwater from the previous rainy season; 9 (2%) households reported using bottled drinking water; and 24% of households used ‘improved’ water sources as defined by the UNICEF/WHO Joint Monitoring Programme. The distribution of prevalent drinking water sources varied by region. Respondents were asked to estimate the distance to the primary drinking water source: 340 (67%) sources were within 100 m, 128 (25%) were between 100 and 500 m and 38 (8%) were more than 500 m away.

All households 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 (unsafe storage). Containers were most commonly ceramic or concrete traditional design vessels. Respondents were asked to demonstrate the usual method of collecting water from the container for drinking.

Table 1 | Data summary and estimated odds ratios for selected factors. Odds ratios are adjusted for time elapsed since implementation

	Using filter* at time of follow up (156 households)	Not using filter at time of follow up (350 households)	OR (95% CI) adjusted†
Caregiver reported receiving health education‡	31 (20%)	83 (24%)	0.74 (0.42–1.3)
Soap observed in household§	119 (76%)	220 (63%)	1.7 (1.0–3.0)
Purchased filter¶	112 (72%)	99 (28%)	2.1 (1.2–3.7)
Living on less than US\$1 per day per person in household¶	49 (31%)	186 (53%)	0.68 (0.42–1.2)
Access to sanitation**	102 (65%)	92 (26%)	2.4 (1.5–4.0)
Safe storage practices observed††	118 (76%)	224 (64%)	1.6 (0.94–2.7)
Caregiver reports washing hands 'always'‡‡	76 (49%)	100 (29%)	1.6 (1.0–2.6)
Main drinking water sources during study (dry season)§§			
Surface water	98 (63%)	145 (41%)	1.7 (1.1–2.7)
Groundwater	41 (26%)	190 (54%)	0.56 (0.34–0.94)
Deep well (≥ 10 m)	14 (9%)	65 (19%)	0.38 (0.18–0.79)
Shallow well	27 (17%)	125 (36%)	0.91 (0.50–1.7)
Rainwater	23 (15%)	16 (5%)	1.4 (0.64–3.0)
Bottled water	2 (1%)	7 (2%)	0.53 (0.08–3.4)
Observed method of collecting household stored water¶¶			
Use hands	70 (45%)	150 (43%)	0.90 (0.56–1.4)
Pour, tap, or designated dipper	86 (55%)	200 (57%)	
Months since implementation¶¶¶			
0–5	49 (31%)	8 (2%)	0.56 (0.50–0.63)
6–11	12 (8%)	3 (1%)	(per 6 month increase)***
12–17	16 (10%)	16 (5%)	
18–23	32 (21%)	31 (9%)	
24–29	14 (9%)	30 (9%)	
30–35	6 (4%)	29 (8%)	
36–41	11 (7%)	112 (32%)	
42–48	14 (9%)	96 (27%)	
Unknown	2 (1%)	25 (7%)	

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

†Odds ratios adjusted for time since implementation coded as a categorical variable in 6 month blocks, except ***.

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

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

¶Any price. Prices paid for filters ranged from 1,000 to 10,000 riel (US\$0.25–2.50). Actual cost is US\$4–8.

¶Based on self-reported monthly income and number of members in household.

**Shared or own latrine.

††Safe storage was defined as using a covered or narrow mouth water storage container and a designated water dipper to collect water.

‡‡Caregiver responds that she or he washes hands 'always' with soap at critical points such as after defecating.

§§Multiple answers possible.

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

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

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.

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 was 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 some communities. Therefore, households that 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%) household caregivers indicated that they washed hands 'always' with soap and water at critical points such as after defecating or before preparing food. 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 per cent of study respondents indicated that diarrhoea is a serious illness for children, while 81% of respondents reported that water is an important route of disease transmission. These basic health messages, along with instructions on proper use and regular maintenance of the filters, accompanied most implementation programmes for the filters in the study areas.

Of the 506 households included 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 1; Figure 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 water uses. Users reported filling the filter an average of 1.8 times per day and cleaning it 2.3 times per week. The filter was used only for drinking water by 133 (86%) households. Although flow rates in the field were not measured, all filters leaving the factories fall within the range of 1.0–3.0 litres per hour as a QA/QC step. Flow rates in household use vary with degree of clogging as a function of turbidity and cleaning frequency, and hydraulic head.

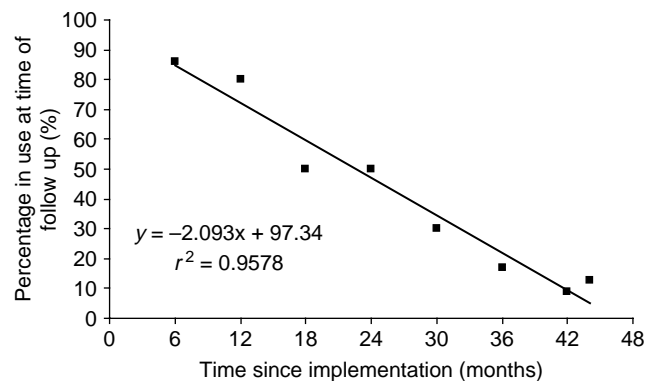


Figure 2 | Percentage of filters remaining in household use as a function of time, with time as a categorical variable (6-month increments).

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 CWP; the mean non-zero response ($n = 106$) was 9,500 riel (US\$2.38): 5,900r (US\$1.48) in Kandal, 6,700r (US\$1.68) in Kampong Chhnang and 11,800r (US\$2.95) in Pursat. Households that were successfully using the filter on a daily basis were asked about purchasing additional or replacement ceramic filter inserts: 72% of respondents were willing to pay US\$2.50, 29% were willing to pay US\$4 and 26% were willing to pay US\$5. The cost of replacement ceramic filter elements in Cambodia is currently in the US\$2.50–5.00 range.

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

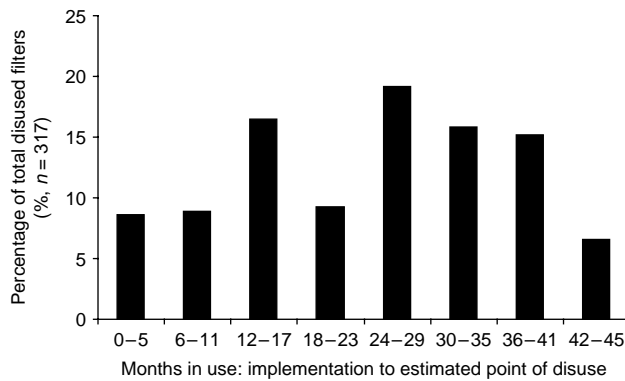


Figure 3 | Histogram showing the distribution of user-approximated time in use of filters not in use at the time of this follow-up study ($n = 317$).

provinces within 20 km from the intervention locations. Whether these distribution points were readily accessible to respondents was not clear, however, owing to the high cost of transport and seasonal accessibility of roads.

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 estimates were possible, 253 (53%) were reliably dated using questionnaire or filter data and the remaining were dated by user estimation, which was probably less accurate. Broken filters were often no longer available to inspect. The manufacturing date could not be discerned on many of the oldest filters because of surface wear. Users were asked to approximate, if possible, the date that the family stopped using the filter to the nearest month.

Twenty-seven filters, 5% of the total, could not be dated confidently by any means. Distribution of time-in-use data in 6-month increments is presented in Figure 3; filters were in used in households for about 2 years, on average.

Of the 350 filters no longer in use, 328 households provided responses when asked why their filter was out of use. A total of 214 (65%) reported filter unit breakage, either of the ceramic filter element, the spigot or the container (Figure 4). The remaining third of respondents gave the following reasons for disuse: the filter was too slow or otherwise unable to meet the household drinking water demand (5%); the filter had passed its recommended useful life as indicated by the NGO manufacturer, and so users assumed it was no longer effective (5%); the householder had given or sold the filter to a friend or relative (3%); or other reasons. A number of users reported having repaired the containers or taps on their own using locally available replacement parts (buckets and taps).

The most important predictor of the proportion of filters remaining in household use is time since implementation (Table 1, Figure 5). 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 2 indicates an average fall-off in use of approximately 2% per 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 behaviours in the household. With

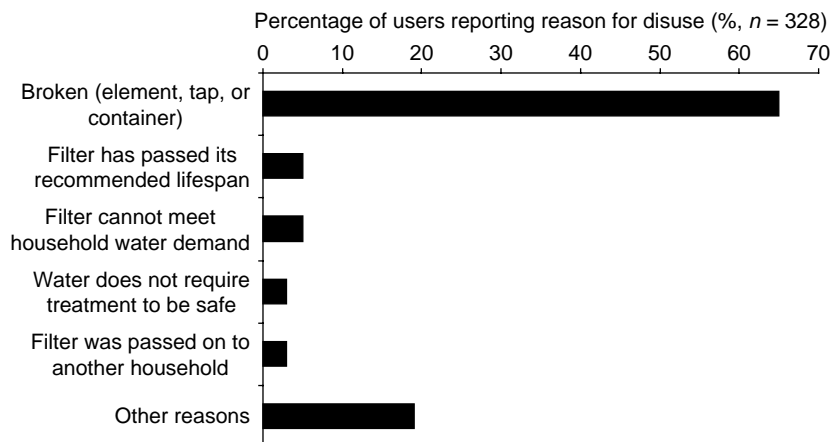


Figure 4 | Reasons given by respondents for filter disuse at the time of follow up.

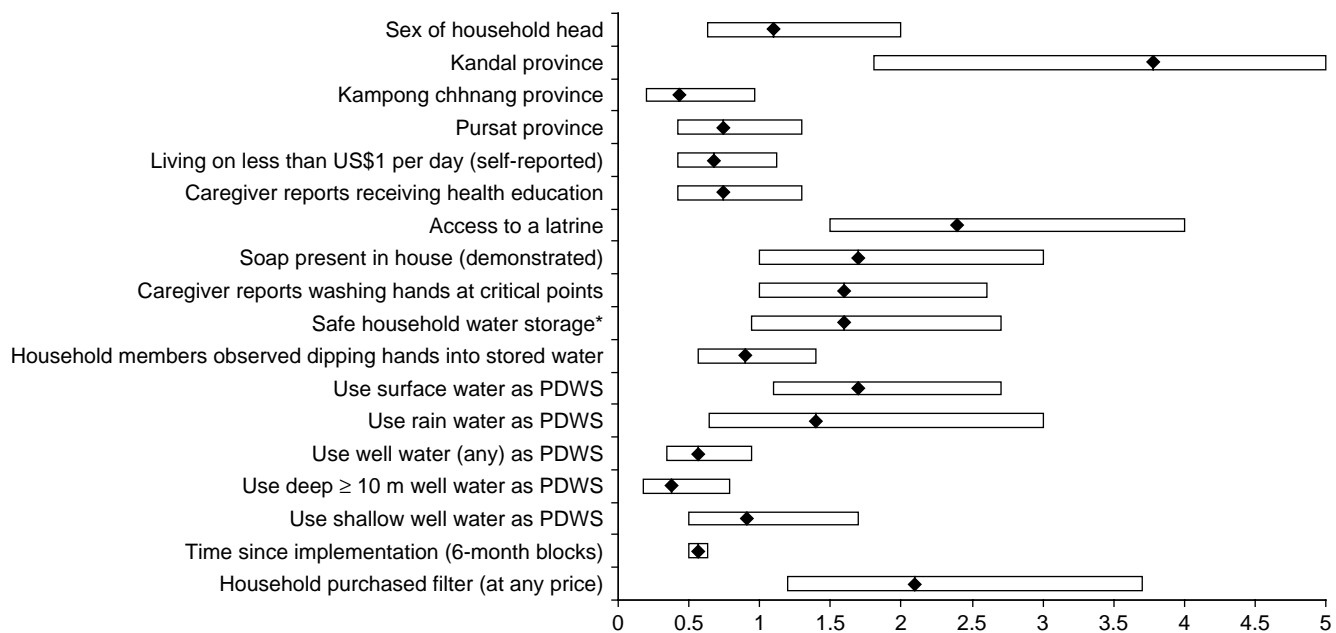


Figure 5 | Odds ratio (OR) point estimates (and 95% confidence intervals) for factors associated with continued use of the CWP in 506 households in Kandal, Kampong Chhnang and Pursat Provinces, adjusted for time since implementation (PDWS = primary drinking water source (non-exclusive); *covered household water storage container observed).

respect to water source, households that reported ground-water use from deep wells (defined here as ≥ 10 m) were less likely to use the filter (OR: 0.38, 95% CI 0.18–0.79) after controlling for time since implementation. 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). 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 for free. Cash payments for the filters ranged from 1,000 to 10,000 riel (US\$0.25–2.50). No clear trend was observed between filter use and the level of cash investment.

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), the household caregiver reporting that she or he always washed

hands with soap and water at critical points such as 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 (safe storage) 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 caregivers reporting water-related health and hygiene education (OR: 0.74, 95% CI 0.42–1.3). Observed associations do, however, suggest a relationship between filter use and knowledge of positive household health and hygiene practices. Other potentially important demographic and socio-economic predictors of filter use were also examined. Sex of household head (OR 1.1, 95% CI 0.63–2.0) and reported household income (OR: 0.68, 95% CI 0.42–1.1) were not associated with the outcome of continued filter use after controlling for time since implementation.

DISCUSSION

Results suggest that ceramic water filters are more likely to be used by households that (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) do not use deep wells (≥ 10 m) 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 or awareness of distribution points may limit the sustainability of ceramic filter intervention efforts. Despite the declining use of the intervention, user satisfaction with the filters was generally very high, and a high percentage of users reported a willingness to purchase additional filters or replacement parts. Time in use for filters in households was about 2 years, on average, before disuse. 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.

Because these data are cross-sectional and retrospective for use data from several interventions over 44 months, it would be incorrect to describe the 2% decline in use per month post-implementation as a fall-off rate, although evidence (Figure 2) suggests that there is a linear association between use and time that transcends differences in implementation models or other locally variable factors. No filter implementations took place where users had access to replacement filters or parts, so these data may not represent situations where replacements are available to users.

The declining use 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). Several studies have examined uptake of interventions for household water use and safe storage by measuring continued use of the technology or method (Luby *et al.* 2001; Mong *et al.* 2001; Parker *et al.* 2006; Clasen *et al.* 2006). Often uptake and use of technologies is a complex process that involves many socio-cultural factors (Wellin 1955; Rogers 2003). There is some evidence that this is a major factor limiting the success of household water treatment, for all technologies. More research is needed on the long-term

sustainability of this strategy for providing access to safe water, although some method of household water treatment may be the only option for many lacking access to this basic need.

Anecdotal evidence in the study region suggests that low flow rates and rapid clogging of ceramic filters can be associated with the use of groundwater from deep wells; these factors may explain the lower use of CWPs among those using deep wells as a primary water source. This may be the result of insoluble ferric (Fe^{3+}) iron formation from dissolved Fe^{2+} , which occurs in high concentrations in many Cambodian groundwaters (Feldman *et al.* 2007). The same association was not observed with households reporting use of shallow wells (OR: 0.91, 95% CI 0.50–1.7), possibly because Fe oxidation and precipitation occurs in the water of open wells before water is drawn. Interviews with participating study households confirmed that water from deep well sources is also perceived to be potable without further treatment. The fact that users of surface water were more likely to continue using the filters suggests that water quality perception may drive use of the intervention. In this study, 89.5% of respondents indicated that aesthetic qualities of the water were a primary reason for treating it while 45% cited health reasons.

CONCLUSIONS

The rate of filter disuse was approximately 2% per month after implementation, largely owing to breakages. There was a strong association between filter use and time since implementation. Uptake and long-term use of the ceramic water purifier in Cambodia can be aided by scaling up access to replacement parts and filters, since filters can break and there is strong demand for replacements in the intervention areas. 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.

ACKNOWLEDGEMENTS

This research was made possible by funding from UNICEF and WSP-World Bank. The views expressed in this paper are the views of the authors and do not necessarily reflect the views or policies of the United Nations Children's Fund or the Water and Sanitation Programme. We thank Uon Virak, Choun Bunnara, Lim Kimly, Oum Sopharo, Song Kimsrong, and Van Sokheng for conducting interviews; RDIC and IDE for logistical support; and the Cambodian families who generously opened their homes to us.

REFERENCES

- AFA Guatemala 1995 Contra la morbilidad infantil: filtros artesanales y educación. *Revista de Estudios Sociales* Monograph 53(4). Instituto de Investigaciones Económicas y Sociales, Universidad Rafael Landívar, Guatemala (in Spanish).
- Brown, J., Sobsey, M. & Loomis, D. 2008 Local drinking water filters reduce diarrheal disease in Cambodia: a randomized, controlled trial of locally made ceramic filters. *Am. J. Trop. Med. Hyg.* **79**(3), 394–400.
- Clasen, T., Brown, J. & Collin, S. 2006 Preventing diarrhoea with household ceramic water filters: assessment of a pilot project in Bolivia. *Int. J. Environ. Health Res.* **16**(3), 221–239.
- Duke, W. F., Nordin, R. & Mazumder, A. 2006 *Comparative Analysis of the Filtrón and Biosand Water Filters*. Monograph available at: http://pottersforpeace.org/wp-content/uploads/comparative_analysis_of_the_filttron_and_biosand_water_filterseditms.pdf (accessed 1 April 2008).
- Feldman, P., Rosenboom, J. W., Mao, S., Chea, S., Peng, N. & Iddings, S. 2007 Assessment of the chemical quality of drinking water in Cambodia. *J. Water Health* **5**(1), 101–116.
- Lantagne, D. 2001 *Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter—Report 2: Field Investigations*. Alethia Environmental, Allston, Massachusetts. Monograph available at: http://s189535770.onlinehome.us/pottersforpeace/?page_id=25 (accessed 1 April 2008).
- Luby, S., Agboatwalla, M., Raza, A., Sobel, J., Mintz, E., Baier, K., Rahbar, M., Qureshi, S., Hassan, R., Ghouri, F., Hoekstra, R. M. & Gangarosa, E. 2001 A low-cost intervention for cleaner drinking water in Karachi, Pakistan. *Int. J. Infect. Dis.* **5**, 144–150.
- Mattelet, C. 2006 *Household Ceramic Water Filter Evaluation Using Three Simple Low-Cost Methods: Membrane Filtration, 3M Petrifilm, and Hydrogen Sulfide Bacteria in Northern Region, Ghana*. MS Thesis, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology.
- Mong, Y., Kaiser, R., Ibrahim, D., Rasoatiana, R. L. & Quick, R. E. 2001 Impact of the safe water system on water quality in cyclone-affected communities in Madagascar. *Am. J. Public Health* **91**(10), 1577–1579.
- Oyanedel-Craver, V. A. & Smith, J. A. 2008 Sustainable colloidal-silver-impregnated ceramic filter for point-of-use water treatment. *Environ. Sci. Technol.* **42**, 927–933.
- Parker, A. A., Stephenson, R., Riley, P. L., Ombeki, S., Komolleh, C., Sibley, L. & Quick, R. 2006 Sustained high levels of stored drinking water treatment and retention of hand-washing knowledge in rural Kenyan households following a clinic-based intervention. *Epidemiol. Infect.* **134**(5), 1029–1036.
- Roberts, M. 2004 Field test of a silver-impregnated ceramic water filter. *30th WEDC International Conference*, Vientiane, Lao PDR. Available online at: <http://wedc.lboro.ac.uk/conferences/pdfs/30/Roberts.pdf> (accessed 28 November 2008).
- Rogers, E. 2003 *Diffusion of Innovations*, 5th edition. Simon and Schuster, New York.
- Sobsey, M. D. 2002 Managing Water in the Home: Accelerated Health Gains from Improved Water Supply. World Health Organization, Geneva. Available at: http://www.who.int/water_sanitation_health/dwq/wsh0207/en/index.html
- Van Halem, D. 2006 *Ceramic Silver Impregnated Pot Filters for Household Drinking Water Treatment in Developing Countries*. Master's Thesis, Faculty of Civil Engineering. Delft University of Technology, Netherlands.
- Wellin, E. 1955 Water boiling in a Peruvian town. In *Health, Culture, and Community* (ed. B. D. Paul), pp. 71–103. Russell Sage Foundation, New York.

First received 2 August 2008; accepted in revised form 11 October 2008. Available online May 2009