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Boiling as Household Water Treatment in Cambodia: A Longitudinal Study of Boiling Practice and Microbiological Effectiveness

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Abstract. This paper focuses on the consistency of use and microbiological effectiveness of boiling as it is practiced in one study site in peri-urban Cambodia. We followed 60 randomly selected households in Kandal Province over 6 months to collect longitudinal data on water boiling practices and effectiveness in reducing *Escherichia coli* in household drinking water. Despite > 90% of households reporting that they used boiling as a means of drinking water treatment, an average of only 31% of households had boiled water on hand at follow-up visits, suggesting that actual use may be lower than self-reported use. We collected 369 matched untreated and boiled water samples. Mean reduction of *E. coli* was 98.5%; 162 samples (44%) of boiled samples were free of *E. coli* (< 1 colony-forming unit [cfu]/100 mL), and 270 samples (73%) had < 10 cfu/100 mL. Storing boiled water in a covered container was associated with safer product water than storage in an uncovered container.

INTRODUCTION

Boiling is the most common method for treating small quantities of water globally, with an estimated 1.2 billion people using it as a means of household water treatment (HWT).[1–3] It has the advantages of being widely accessible and effective against all classes of pathogens if done correctly,[4] although it may be locally expensive, energy-intensive, and more environmentally costly than other options for water treatment. It is also, in many places, an ingrained cultural practice. In some countries, such as Indonesia,[5] it is a practice with a long history of government promotion. Boiling has been proposed as the standard HWT method against which other methods should be compared or judged.[6]

Field studies of boiling as it is actually practiced by households have suggested that it may be very effective in reducing microbial indicators, but treated water may also be susceptible to recontamination if stored improperly,[1,4,7–9] such as in wide-mouth or uncovered containers or if it comes into contact with users' hands during storage or access.[5] Post-treatment recontamination from unsafe storage may, therefore, limit the effectiveness of boiling *in situ*.[5,8,10]

Another limiting factor for boiling and indeed, all other methods of HWT may be adherence (consistent, correct, and sustained use) over time, which may be associated with health impact.[11–14] In cases where the alternative to treated water may be high-risk water, exclusive use of water treatment may be critical to reducing overall risk.[11,15] According to the most recent Demographic and Health Survey (DHS) in Cambodia, 66.8% of households reported boiling as a means of water treatment.[16] These estimates, however, are derived from self-report questionnaires and may not accurately reflect the actual use of boiling to treat some or all household drinking water consistently over time.[1]

The purpose of this study was to examine boiling frequency, adherence, and microbiological effectiveness over a 6-month period in a random selection of 60 households in periurban Cambodia.

METHODS

Sixty randomly selected households were included in this study. Eligibility criteria for participation were that households (1) were willing to voluntarily participate, (2) were within a pre-determined study area of one village in Kandal Province, (3) stored water in the home, (4) had a child of less than 5 years of age as a household member at the first household visit, and (5) did not use commercially produced bottled water as a primary source of household potable water. A list of all households from current commune records was used for random sampling, and randomly selected households were visited in random order to determine eligibility. Approximately 50% of all households visited were eligible. Those households that were eligible were presented with information about the study and informed consent.

Informed consent was obtained from the appropriate family member. This person was usually the female head of household (either responsible for or knowledgeable of household water management practices) who acted as the main respondent for the home in subsequent visits. The consent form was translated into Khmer and then back-translated into English, and it was piloted to ensure clarity before use in the field. Surveys used simple, straightforward language with predominantly closed (multiple choice) questions. The data collection (field) team was composed of four interviewers who were native speakers of Khmer and had related experience in community health data collection in the study area. 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, University of North Carolina at Chapel Hill and the Ministry of Rural Development, Kingdom of Cambodia.

Households were asked to continue their normal water collection, use, and handling practices during the study. Households were followed for a period of 6 months with approximately biweekly follow-up visits (11 in total). We asked respondents whether they practiced boiling or any other water treatment method, frequency of boiling, storage practices for boiled water, whether there was any boiled water in the house, and whether we could examine it. If boiled water was hot to the touch or still boiling, we noted the fact. If the boiled water was not hot to the touch, we requested 250-mL samples of both

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the boiled water and the respondent-identified pretreatment water, which was generally stored household water. We asked the respondent to fill the sample containers as they would a drinking water cup to observe the collection method from the storage vessel. Samples were kept cool and transported to the laboratory in Kien Svay, Kandal Province, where analysis was performed as soon as possible (in all cases, within 24 hours). *Escherichia coli* in pre- and post-treatment samples were enumerated by filtering undiluted and diluted samples through 47-mm diameter, 0.45-μm pore size cellulose ester filters in standard, sterile magnetic membrane filter funnels, and membranes were incubated on agar or broth media-soaked absorbent pads. Agar and broth media (M1465/M1453, Rapid HiColiform media; HiMedia, Mumbai, India) were used to detect *E. coli*.[17–19] Plates were incubated for 20–24 hours at 35°C. These methods conform to the US Environmental Protection Agency (EPA) Approved Method 1604,[20] except that locally available HiMedia M1465 and M1453 were substituted for the more costly MI medium used in the EPA method. In preliminary studies in which samples were plated on both media (MI and M1465 or M1453), *E. coli* detection was comparable (data not shown). *E. coli* concentrations were expressed as colony-forming units (cfu) per 100 mL. Turbidity of water samples was measured in triplicate using a turbidimeter (Hach®, Loveland, CO), and the average values were reported as nephelometric turbidity units (NTUs).

In addition to data collected on household water management and water quality, we collected additional data on factors potentially associated with household water quality and treatment, primarily because of previous studies[4] and local anecdotal evidence that boiled water is often recontaminated after treatment, a process that could be related to hand hygiene, sanitation, and other factors of potential importance in the fecal–oral transmission of disease. We asked about and observed practices related to water collection, treatment, storage, and use, and we documented sanitation and hygiene conditions and practices.

We measured households' consistency of access to boiled water as the percentage of the 11 household visits during which there was boiled water either in preparation, cooling, or available for drinking. Households were visited between 08:00 and 17:00 on weekdays at roughly 2-week intervals. Households were not alerted before the visit.

Descriptive statistics were used to characterize water quality testing results, including geometric and arithmetic means (with 95% confidence intervals [CIs]), standard deviation, and variance of $\log_{10}$ reduction of *E. coli*. Parametric and non-parametric statistical tests were used to compare results where appropriate. Statistical testing was performed in Stata version 8.1 (Stata Corporation, College Station, TX).

RESULTS

Ninety percent of randomly selected households surveyed reported boiling water daily as a means of household water treatment. Of these 54 households, 33% said they typically boiled drinking water only one time per day, 35% reported boiling two times, 16% boiled three times, 10% boiled four times, and 6% boiled five times.

Over the course of the 6-month study, few households had boiled water consistently available for drinking or being prepared at the time of our visits, with only two households (3%)

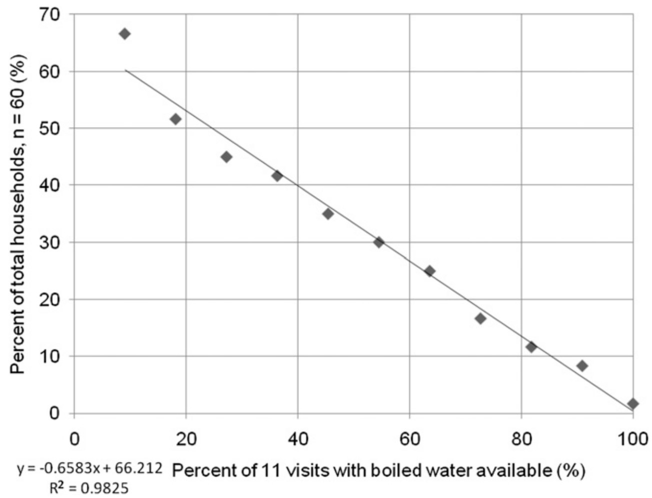

FIGURE 1. Percentage of total households having boiled water in preparation or available for drinking at follow-up visits.

having boiled water at all 11 household visits. The percentage of households with boiled water on hand in the household during unannounced visits varied between 23% and 38% (mean = 31% at each cross-section). Figure 1 shows that, although 66% of households had boiled water available or being prepared on at least one visit, a lower percentage of households had boiled water for multiple unannounced visits. We found no association between households' self-reported frequency of boiling and the probability that the household would have boiled water on hand at the time of follow-up visits by analysis of variance (ANOVA; $P = 0.53$).

The distributions of *E. coli* counts in 100-mL treated water samples are given in Figure 2. For boiling, arithmetic mean *E. coli* counts per 100 mL were 100 (95% CI = 60–140) and geometric mean counts were 17 (95% CI = 13–22) against arithmetic and geometric mean pre-treatment concentrations of 3,000 (95% CI = 2,100–3,800) and 490 (95% CI = 400–590), respectively.

Boiling resulted in significant reductions of *E. coli* in household stored water (Figures 2, 3 and Table 1). Treatment by boiling (N = 369 paired samples of treated and untreated water) resulted in an arithmetic mean 1.8 $\log_{10}$ reduction in *E. coli* (95% CI = 1.7–2.0) or 98.5%. The calculation of $\log_{10}$ reduction of *E. coli* in field samples is limited by non-detects in the treated water (*E. coli*/100 mL < 1 cfu), resulting in $\log_{10}$

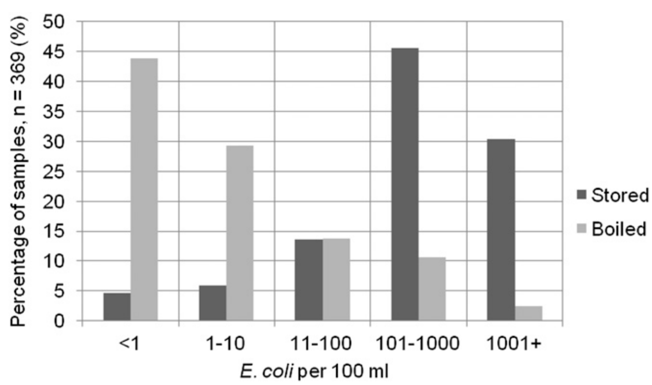

FIGURE 2. Order of magnitude categories of *E. coli* counts per 100 mL in household stored (untreated) and boiled water.

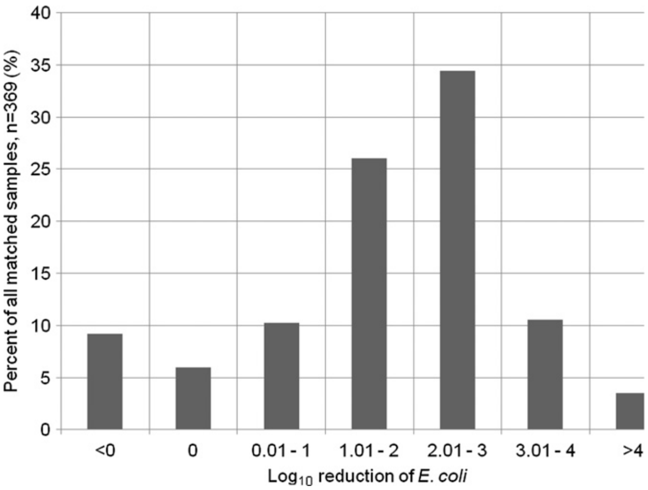

FIGURE 3. Histogram frequency distribution of $\log_{10}$ reduction of *E. coli* by boiling. Arithmetic mean: 1.8 (95% CI = 1.7–2.0, N = 369); 34 sample sets (9.2%) produced water of worse apparent quality than untreated water ($\log_{10}$ reduction of *E. coli* < 0).

reduction values that are a function of the measured *E. coli* in the untreated water sample only. This finding was the case for 149 samples (40% of all samples), suggesting that calculated mean $\log_{10}$ reductions represent conservative estimates of the treatment efficiency of boiling in reducing *E. coli*.

In 21 samples (6%), the measured levels of *E. coli* in the untreated water and product water were both < 1 cfu/100 mL, resulting in a calculated log-reduction value (LRV) of zero. There was a substantial difference in the calculated $\log_{10}$ reduction of *E. coli* between matched samples that were limited by untreated water *E. coli* counts of < 1 cfu/100 mL and those samples that had detectable *E. coli* in boiled water samples. The arithmetic mean $\log_{10}$ reduction of *E. coli* was 2.2 (95% CI = 2.2–2.6 or 99.4%) among samples with *E. coli* non-detects in post-treatment water versus 1.4 $\log_{10}$ (95% CI = 1.2–1.5 or 96%) for those samples with detectable *E. coli* in post-treatment water, a difference of 0.80 $\log_{10}$ (P < 0.0001). Log_{10} reduction of *E. coli* was greater in surface waters (2.0; 95% CI = 1.8–2.2) and rain waters (1.9; 95% CI = 1.6–2.1) than well waters (1.5; 95% CI = 1.2–1.8), consistent with the fact that untreated water quality sourced from wells had generally less *E. coli* before treatment than other sources, such as surface water or rainwater. The arithmetic mean turbidity in stored, boiled water samples was 8.2 NTU (95% CI = 6.7–9.7), versus 7.8 NTU (95% CI = 6.6–9.1) for matched stored household water samples. Boiled water samples were not significantly more or less turbid than household stored water samples.

A variety of covered and uncovered water storage containers were observed to be in use. Approximately one-half of stored boiled water samples (N = 188; 51%) came from a covered container; about one-half of respondents filled the sample container by pouring from the boiled water vessel (N = 189; 51%), and one-half of respondents used a dedicated dipper (N = 180; 49%). Storing boiled water in a covered container was associated with safer product water (< 1 *E. coli* per 100 mL versus ≥ 1 *E. coli* per 100 mL; odds ratio [OR] = 0.66, 95% CI = 0.45–0.96, P = 0.028). No association was observed between the respondent's method of filling the sample container and *E. coli*. Of 369 paired samples, 34 (9.2%)

TABLE 1
Field effectiveness of water treatment by boiling and storage for all samples

		Water source*			Drinking water storage container		Observed drinking water collection method	
	All† (n = 369)	Rain water (N = 137)	Surface water (N = 130)	Well water (N = 93)	Covered (N = 181)	Uncovered (N = 188)	Pouring (N = 189)	Dipping (N = 180)‡
Arithmetic means for *E. coli*								
Mean pre-treatment ($\log_{10}$ units)§	2.5 (2.4–2.6)	2.6 (2.4–2.8)	2.5 (2.3–2.7)	2.3 (2.1–2.6)	2.5 (2.3–2.6)	2.6 (2.4–2.7)	2.5 (2.3–2.7)	2.5 (2.4–2.7)
Mean boiled water ($\log_{10}$ units)§	0.69 (0.59–0.78)	0.76 (0.61–0.91)	0.49 (0.36–0.62)	0.84 (0.63–1.1)	0.66 (0.53–0.79)	0.71 (0.57–0.85)	0.63 (0.51–0.75)	0.72 (0.58–0.87)
LRV mean¶ (95% CI)	1.8 (1.7–2.0)	1.9 (1.6–2.1)	2.0 (1.8–2.2)	1.5 (1.2–1.8)	1.8 (1.6–2.1)	1.9 (1.7–2.0)	1.9 (1.7–2.1)	1.8 (1.6–2.0)
LRV SD (variance)	1.3 (1.7)	1.3 (1.6)	1.2 (1.5)	1.4 (1.8)	1.3 (1.7)	1.3 (1.6)	1.5 (1.5)	1.4 (1.9)
Geometric means for *E. coli*								
Mean pre-treatment ($\log_{10}$ units)§	2.7 (2.7–2.8)	2.8 (2.6–2.9)	2.8 (2.6–2.9)	2.6 (1.5–2.8)	2.7 (2.6–2.8)	2.7 (2.6–2.8)	2.7 (2.6–2.8)	2.8 (2.7–2.9)
Mean boiled water ($\log_{10}$ units)§	0.98 (0.87–1.1)	0.97 (0.82–1.2)	0.76 (0.61–0.94)	1.2 (1.0–1.5)	0.90 (0.76–1.1)	1.1 (0.92–1.3)	0.96 (0.82–1.1)	0.98 (0.82–1.2)
LRV mean¶ (95% CI)	1.9 (1.73–2.0)	1.8 (1.5–2.2)	2.2 (2.0–2.4)	1.6 (1.2–1.9)	1.8 (1.6–2.1)	1.9 (1.8–2.1)	1.8 (1.6–2.0)	1.9 (1.7–2.2)

* Self-reported sources of water subjected to boiling. In nine instances (2.4%), the source could not be identified by the respondent.
† Number of matched raw/treated water samples.
‡ Possible contact with hands.
§ Concentration (arithmetic mean) per 100 mL sample ($\log_{10}$ units).
¶ Arithmetic mean LRV = $\log_{10}$ (pre-treatment concentration/post-treatment concentration).
Data summary of $\log_{10}$-transformed *E. coli* counts per 100 mL sample.

had higher levels of *E. coli* per 100 mL in the post-treatment water, suggesting recontamination or regrowth in storage.

The mean time that a respondent reported spending boiling her or his water was 20 minutes (range = 5–50 minutes), a time that was exclusive of gathering or purchasing fuel or waiting for the water to cool before consumption. Of the 60 responding households, 54 (90%) used primarily firewood (purchased or gathered), 5 (8%) used charcoal, and 1 (2%) used kerosene.

DISCUSSION

This study presents a snapshot of boiling practice in one Cambodian community over a 6-month period in 2006. These findings may not be generalizable to other settings, but they do suggest that a careful consideration of user behavior may be necessary to understand whether and how boiling may be providing safe drinking water outside of an intervention context.

According to the 2010 DHS survey,[16] 66.8% of households (65.1% rural and 75.0% urban) reported boiling as a means of household water treatment, and it is, by far, the most prevalent method for water treatment before consumption, with filtration (ceramic, sand, or other) in a distant second at 10.7% (all households). The actual questions used in the survey were "do you do anything to the water to make it safer to drink?" and "what do you usually do to make the water safer to drink?". Respondents were not prompted to answer boiling as a specific practice.[21] In our survey, we used a closed-type question that included boiling as a choice, which could explain why we received the answer of "yes, one or more times per day" from 90% (N = 54) of respondents. Nevertheless, the much lower percentage of households that we found who had boiled water on hand or being prepared suggests that both question types may not reliably estimate the frequency of boiling in practice. Findings from previous studies comparing reported and actual use of water treatment have also suggested that self-report may overestimate use.[22]

These results seem to indicate that self-reporting of boiling is unreliable. If boiled water is not on hand, it is not available for drinking at that time by members of the household. Counting users of HWT in context may require more reliable measures of tracking consistency of use as well as observed behaviors if we aim to understand the effectiveness of water quality interventions used in practice.[1,2]

Recent evidence suggests that adherence (correct, consistent, and sustained use of water quality interventions) is an important consideration for translating the potential of HWT to health impacts.[11–13] By this measure, boiling as a means of HWT in this population may not be consistently protecting users' health, but its widespread use may make it a scaleable practice. More research is needed to characterize how households make the decision to treat water and what conditions or circumstances prevent or promote more consistent use over time. A number of studies have highlighted the fact that high adherence may not be assumed for household water treatment practices.[10,23–26]

Water quality results reported here are generally consistent with recent studies of the effectiveness of boiling in reducing thermotolerant coliforms (TTC) by 86–99%.[6,7,9,27] We calculated a mean reduction of *E. coli* of 98.5% in stored boiled water samples (arithmetic mean = 1.8 $\log_{10}$, N = 369) (Table 1). Negative $\log_{10}$ reduction values occurred in 34 sample sets of boiled water (9.2% of total) when comparing *E. coli* counts in untreated with treated water, indicating higher levels in the treated water. The observation of increased levels of *E. coli* in treated water may be related to improper handling or water storage methods, changing levels of *E. coli* in water over time (including the possibility of regrowth in the treated water),[28] die off in the untreated water, or other factors. These results are consistent with several studies[29,30] showing that recontamination of stored water in the home could significantly impact the quality of potable water used in the household. Apart from noting that boiled water stored in covered containers was associated with improved microbial water quality, we did not identify any associations with other measured factors. We did not attempt to ascertain the elapsed time from boiling until sampling, which may influence the presence and levels of *E. coli* or other fecal indicator bacteria in the treated and stored water.

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REFERENCES

1. Rosa G, Clasen T, 2010. Estimating the scope of household water treatment in low- and medium-income countries. *Am J Trop Med Hyg 82:* 289–300.
2. Yang H, Wright JA, Gundry SW, 2012. Household water treatment in China. *Am J Trop Med Hyg 86:* 554–555.
3. Rosa G, Clasen T, 2012. In response. *Am J Trop Med Hyg 86:* 556.
4. Sobsey MD, 2002. *Managing Water in the Home: Accelerated Health Gains from Improved Water Supply*. Geneva: World Health Organization.
5. Sodha SV, Menon M, Trivedi K, Ati A, Figueroa ME, Ainslie R, Wannemuehler K, Quick R, 2011. Microbiologic effectiveness of boiling and safe water storage in South Sulawesi, Indonesia. *J Water Health 9:* 577–585.
6. Clasen T, McLaughlin C, Nayaar N, Boisson S, Gupta R, Desai D, Shah N, 2008. Microbiological effectiveness and cost of disinfecting water by boiling in semi-urban India. *Am J Trop Med Hyg 79:* 407–413.
7. Clasen TF, Thao do H, Boisson S, Shipin O, 2008. Microbiological effectiveness and cost of boiling to disinfect drinking water in rural Vietnam. *Environ Sci Technol 42:* 4255–4260.
8. Luby SP, Syed AH, Atiullah N, Faizan MK, Fisher-Hoch S, 2000. Limited effectiveness of home drinking water purification efforts in Karachi, Pakistan. *Int J Infect Dis 4:* 3–7.
9. Psutka R, Peletz R, Michelo S, Kelly P, Clasen T, 2011. Assessing the microbiological performance and potential cost of boiling drinking water in urban Zambia. *Environ Sci Technol 45:* 6095–6101.
10. Gupta SK, Suantio A, Gray A, Widyastuti E, Jain N, Rolos R, Hoekstra RM, Quick R, 2007. Factors associated with *E. coli* contamination of household drinking water among tsunami and earthquake survivors, Indonesia. *Am J Trop Med Hyg 76:* 1158–1162.
11. Brown J, Clasen T, 2012. High adherence is necessary to realize health gains from water quality interventions. *PLoS ONE 7:* e36735. doi:10.1371/journal.pone.0036735.

12. Arnold B, Colford J, 2007. Treating water with chlorine at point-of-use to improve water quality and reduce child diarrhea in developing countries: a systematic review and meta-analysis. *Am J Trop Med Hyg 76:* 354–364.
13. Enger KS, Nelson KL, Clasen T, Rose JB, Eisenberg JN, 2012. Linking quantitative microbial risk assessment and epidemiological data: informing safe drinking water trials in developing countries. *Environ Sci Technol 46:* 5160–5167.
14. Waddington H, Snilstveit, White H, Fewtrell L, 2009. *Water, Sanitation and Hygiene Interventions to Combat Childhood Diarrhoea in Developing Countries*. Delhi, India: International Initiative for Impact Evaluation.
15. Hunter PR, Zmirou-Navier D, Hartemann P, 2009. Estimating the impact on health of poor reliability of drinking water interventions in developing countries. *Sci Total Environ 407:* 2621–2624.
16. National Institute of Statistics (NIS), Directorate General for Health, ICF Macro, 2011. *Cambodia Demographic and Health Survey 2010*. Calverton, MD: National Institute of Statistics, Directorate General for Health, and ICF Macro.
17. Manafi M, Kneifel W, 1989. A combined-fluorogenic medium for the simultaneous detection of total coliforms and *E. coli* in water. *Zbl Hyg Umweltmed 189:* 225–234.
18. Manafi M, Kneifel W, Bascomb S, 1991. Fluorogenic and chromogenic substrates used in bacterial diagnostics. *Microbiol Rev 55:* 335–348.
19. Geissler K, Manafi M, Amorós I, Alonso JL, 2000. Quantitative determination of total coliforms and *Escherichia coli* in marine waters with chromogenic and fluorogenic media. *J Appl Microbiol 88:* 280–285.
20. USEPA, 2002. *Method 1604: Total Coliforms and Escherichia coli in Water by Membrane Filtration Using a Simultaneous Detection Technique (MI Medium). Publication EPA-821-R-02–024*, Washington, DC: USEPA Office of Water.
21. WHO/UNICEF, 2006. *Core Questions on Drinking Water and Sanitation for Household Surveys*. Geneva: World Health Organization.
22. Moser S, Heri S, Mosler HJ, 2005. *Determinants of the Diffusion of SODIS. A Qualitative Field Study in Bolivia. Summary Report*. Dubendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (Eawag).
23. Gilman RH, Marquis GS, Ventura G, Campos M, Spira W, Diaz F, 1993. Water cost and availability: key determinants of family hygiene in a Peruvian shantytown. *Am J Public Health 83:* 1554–1558.
24. Quick RE, Kimura A, Thevos A, Tembo M, Shamputa I, Hutwagner L, 2002. Diarrhoea prevention through household-level water disinfection and safe storage in Zambia. *Am J Trop Med Hyg 66:* 584–589.
25. Reller ME, Mendoza CE, Lopez MB, Alvarez M, Hoekstra RM, Olson CA, Baier KG, 2003. A randomized controlled trial of household-based flocculant-disinfectant drinking water treatment for diarrhea prevention in rural Guatemala. *Am J Trop Med Hyg 69:* 411–419.
26. Sobsey MD, Stauber CE, Casanova LM, Brown J, Elliott MA, 2008. Point of use household drinking water filtration: a practical, effective solution for providing access to safe drinking water in the developing world. *Environ Sci Technol 42:* 4261–4267.
27. Rosa G, Miller L, Clasen T, 2010. Microbiological effectiveness of disinfecting water by boiling in rural Guatemala. *Am J Trop Med Hyg 82:* 473–477.
28. Desmarais TR, Solo-Gabriele HM, Palmer CJ, 2002. Influence of soil on fecal indicator organisms in a tidally influenced subtropical environment. *Appl Environ Microbiol 68:* 1165–1172.
29. Wright J, Gundry S, Conroy R, 2004. Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Trop Med Int Health 9:* 106–117.
30. Jensen P, Ensink J, Jayasinghe G, van der Hoek W, Cairncross S, Dalsgaard A, 2002. Domestic transmission routes of pathogens: the problem of in-house contamination of drinking water during storage in developing countries. *Trop Med Int Health 7:* 604–609.