Microbiologic effectiveness of boiling and safe water storage in South Sulawesi, Indonesia
Samir V. Sodha, M. Menon, K. Trivedi, A. Ati, M. E. Figueroa, R. Ainslie, K. Wannemuehler and R. Quick

ABSTRACT
In Indonesia, where diarrhea remains a major cause of mortality among children <5 years, the government promotes boiling of drinking water. We assessed the impact of boiling on water quality in South Sulawesi. We surveyed randomly selected households with at least one child <5 years old in two rural districts and tested source and stored water samples for *Escherichia coli* contamination. Among 242 households, 96% of source and 51% of stored water samples yielded *E. coli*. Unboiled water samples, obtained from 15% of households, were more likely to yield *E. coli* than boiled samples [prevalence ratios (PR) = 2.0, 95% confidence interval (CI) 1.7–2.5]. Water stored in wide-mouthed (PR = 1.4, 95% CI = 1.1–1.8) or uncovered (PR = 1.8, 95% CI = 1.3–2.4) containers, or observed to be touched by the respondent’s hands (PR = 1.6, 95% CI = 1.3–2.1) was more likely to yield *E. coli*. A multivariable model showed that households that did not boil water were more likely to have contaminated stored water than households that did boil water (PR = 1.9, 95% CI = 1.5–2.3). Although this study demonstrated the effectiveness of boiling in reducing contamination, overall impact on water quality was suboptimal. Future studies are needed to identify factors behind the success of boiling water in Indonesia to inform efforts to scale up other effective water treatment practices.

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INTRODUCTION
Diarrheal diseases kill an estimated 1.9 million children under 5 years old each year globally (Boschi-Pinto et al. 2008). WHO estimates that over 880 million people, or 13% of the world’s population, lack access to improved water supplies, an important contributing factor to the diarrheal disease burden (WHO 2008a, b). Tens of millions more are at risk from improved but unsafe drinking water sources. To protect the health of these large populations at risk, a number of point-of-use (POU) water treatment interventions have been developed, field tested and promoted after demonstrating effectiveness at improving microbiologic water quality and preventing diarrhea (Wright et al. 2004; Fewtrell et al. 2005; Arnold & Colford 2007; Clasen et al. 2007; Waddington et al. 2009).

One of the oldest, most widely promoted and most frequently practiced POU method is boiling (Sobsey 2002). Compared with other POU interventions, boiling can be time consuming, costly, and damaging to the environment. Despite this, promotion of boiling in some countries has resulted in widespread use of the practice, particularly among wealthier and less vulnerable populations (Rosa & Clasen 2010). The practice can result in improvement in water quality, but not a complete removal of risk (Clasen et al. 2008a, b; Rosa & Clasen 2010). When practiced correctly, boiling effectively disinfects water; however if not practiced correctly, boiling has minimal impact on water quality (Luby et al. 2000; Gupta et al. 2007).

In Indonesia, boiling has been actively and consistently promoted by the government for decades (Prihartono et al. 1994), yet diarrheal diseases remain the second leading cause of morbidity and mortality among children less than 5 years old (Sunoto 1995; WHO 2008a, b). To explore factors


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influencing the effectiveness of boiling in Indonesia, we examined the impact of boiling on microbiologic quality of stored water in a study of water treatment and storage practices in a population that was participating in an evaluation of a water supply and sanitation program in South Sulawesi, Indonesia in 2007.

METHODS

Evaluation design

For purposes of the water treatment and storage evaluation, we conducted a baseline cross-sectional household survey in villages enrolled in CARE Indonesia’s Sulawesi Water and Sanitation Hygiene (SWASH) program, which was designed to provide water supply and sanitation infrastructure in low-income communities.

In addition to the survey, we tested source and stored water for microbial quality in a 20% subsample of evaluation households. This paper will focus on this subsample.

Evaluation population

We enrolled 48 of 50 low-income communities in Bantaeng and Maros Districts that were targeted for the SWASH program; two were excluded because of poor accessibility. The SWASH program enrolled sets of villages at different times or phases. During March–April 2007, we conducted baseline surveys of 15 communities from Bantaeng and 15 communities from Maros after their enrollment into SWASH phase I. During October–November 2007, we surveyed 7 communities from Bantaeng and 11 communities from Maros after their enrollment into SWASH phase II.

Sample selection

Sample sizes were calculated for the evaluation of water treatment and storage practices in the SWASH population. To conduct this evaluation in SWASH communities, we used population estimates for all 48 communities and determined that we would need to sample approximately 17% of all households. For each community, we randomly selected our starting point and then approached every sixth house for enrollment. Only households with at least one child under 5 years old and a female head of household at least 18 years old were included in the evaluation. If a household refused or did not meet these inclusion criteria, adjacent households were approached until a household was successfully enrolled. Less than 1% of eligible households refused enrollment. Among the approximately 1,200 households enrolled, we selected every fifth for microbiologic testing of source and stored water. This paper focuses on these households.

Data collection

We developed a questionnaire that included information about household demographic and socioeconomic characteristics, water sources and collection, water storage, water treatment, and hygiene and sanitation practices. The questionnaire was translated into Bahasa Indonesia and back-translated into English. Trained local interviewers from the region surveyed the female heads of household.

Water testing and observation

Following the survey, interviewers obtained stored water samples in sterile sample jars by asking the respondent for a glass of drinking water from their usual drinking water container. Interviewers observed the storage containers and water handling practices at the time of sample collection and then asked respondents about the treatment status of the collected sample. Water samples were placed in a cooler on ice and tested within eight hours. We analyzed the samples for contamination by *Escherichia coli* (*E. coli*) using Colilert® tests with Quanti-Trays [www.idexx.com (accessed 15 March 2011)] to determine the most probable number (MPN) estimate of colony counts/100 mL sample. Using this method, the 49 large and 48 small wells in the Quanti-Trays are observed for color changes after incubation with a reagent. The number of positive wells is used to estimate MPN counts that range from 1 to 2,419/100 mL (Edberg et al. 1988).

Data analysis

Questionnaire and laboratory data were entered into Microsoft Access 2003. Analysis was completed using SAS 9.1
software (SAS Institute, Cary, NC) and SUDAAN v10.0. To classify households by a wealth index, we used principal component analysis (PCA) methodology in which household assets were assigned values and then summed to create an asset score for each household (Hatcher 1994). Assets related to water infrastructure, stove type, or fuel source were excluded in the PCA. Asset scores were used to place households into quintiles for data analysis. Consistent with similar studies, we log10-transformed E. coli MPN estimates because of their tendency for a skewed distribution (Clasen et al. 2008a, b; Rosa et al. 2010). To account for the lower and upper limits of detection, we converted MPN findings of <1 to 0.1 and doubled the MPN value for >2,419.6 – 4,839.2.

Log10 reduction between source and stored water samples was estimated by calculating the mean of the difference of the log10 values. Similarly, phase-specific log-reduction estimates were also calculated. Geometric means of source and stored water samples were estimated by calculating the mean and confidence limits on the log10-scale and then transforming back to the original scale. Unadjusted prevalence ratios (PR), model-adjusted PR and corresponding confidence limits were calculated based on the marginal predictions (Bieler et al. 2010). All confidence limits were calculated taking into account stratification (district) and clustering (community) using the Taylor series method of variance estimation in SUDAAN (Binder 1985).

Ethics

We obtained informed consent from all participating households. Institutional review boards at University of Indonesia, Centers for Disease Control and Prevention (protocol 4804), and Johns Hopkins Bloomberg School of Public Health (CHR# H.52.06.02.03.E1) reviewed and approved the protocol.

RESULTS

Demographics and wealth index

A total of 242 households (127 in Bantaeng; 115 in Maros) with 301 children under 5 years old were included in this analysis (Table 1). The median age of respondents was 30 years (range 18–60 years). Of 242 respondents, 72% had a primary school education or less, including 13% with no formal education. The median number of household residents was five (range 2–12).

Of the two project districts, Bantaeng had younger respondents (median age 27), with lower education levels, and was relatively poorer than Maros with 32% in the poorest quintile and 30% in the second poorest quintile. Only 7% were in the wealthiest quintile. In Maros, 7% were placed in the poorest and 10% in the second poorest quintiles, while 33% were in the wealthiest quintile.

Water source, storage and treatment

Among all households, 90% (93% in Bantaeng, 87% in Maros) had improved water sources (Table 2). Only 1% of households had access to municipal water inside the home, but 72% reported having piped water to their home or yard, and 8% reported using a public tap (13% in Bantaeng, 3% in Maros) as the main source of water. When asked in an open-ended fashion about condition or quality of the water source, 59% felt it was ‘clean’; 1% believed it to be ‘dirty’. When asked about safety of the main water source, 98% felt their water was safe to drink.

Narrow-mouthed containers were used for water storage in 50% of households; 97% of containers were observed to be covered.

Among 242 respondents, 214 (88%) reported that they treated their drinking water, 81% in Bantaeng and 97% in Maros (Table 3). Among 214 respondents who treated their water, 212 (99%) reported boiling. When respondents who reported boiling their water were asked about their perceptions of boiling, 83% said boiling was practical, 73% said it was easy, and 90% believed it was cheap. Only 4% felt that boiling was difficult. Among 28 respondents who did not treat water, 10 (36%) said non-treatment of water was a habit while 6 (21%) believed their source water was already safe. Of 27 households with wealth index data available who did not treat water, 20 (74%) were in the poorest three quintiles.

Boiling water

Among 212 respondents who reported boiling water, 92% reported using wood as fuel; 81% of these respondents...
collected the wood themselves. Kerosene was used as a fuel source by 26% of respondents.

**Water testing and observations**

Among 242 households, 231 (96%) source water samples and 122 (51%) stored water samples yielded *E. coli*; 59% of stored water samples in Bantaeng and 42% in Maros yielded *E. coli* (Table 4). Geometric mean *E. coli* counts were 61.3 for source water samples and 1.3 for stored water samples. Analysis of paired water samples for each household showed a 1.7 (95% confidence interval (CI) 1.4–1.9) log$_{10}$ reduction between source and stored water samples. Stratified analysis by time of enrollment showed similar log$_{10}$ reductions for communities in phase one (1.8, 95% CI = 1.5–2.1) and phase two (1.5, 95% CI = 1.2–1.8).

Among 240 stored water samples assessed for *E. coli* MPN, 204 (85%) came from households that reported boiling the sampled water. Among water samples that were not boiled, 89% were contaminated with *E. coli* compared with 44% among boiled samples (prevalence ratio = 2.0, 95% CI = 1.7–2.5); 14% of unboiled samples were severely contaminated (>1,000 MPN of *E. coli*) compared with 3% of boiled samples (Figure 1). The geometric mean *E. coli* count in stored water samples from households that reported not boiling was 29.9 compared with 0.8 in...
water, showed that stored water contamination was independently associated with not boiling (model-adjusted PR = 1.9, CI = 1.5–2.3).

**DISCUSSION**

While most POU studies are research-driven efficacy studies of novel or recently introduced interventions, this study assessed the effectiveness of boiling, an established and widely practiced intervention, as actually practiced by a vulnerable population. In this study, we found that after decades of government promotion of boiling in Indonesia, a high proportion of households in South Sulawesi boiled their water, leading to improved water quality. In the population as a whole, the reduction of *E. coli* contamination from source to stored water among paired household samples was 1.7 log. Among households that reported boiling, the log reduction was even greater at 1.9. Similar log reductions among households that reported boiling were found in three other evaluations: 2.1 in India, 1.5 in Vietnam, and 0.9 in Guatemala (Clasen et al. 2008a, b; Rosa et al. 2010). However, those other studies lacked populations of non-boiling households to evaluate and compare. Our study did include these households and determined that their log reduction was only 0.4.

In other settings, adoption of POU interventions has not been sustainable (Arnold et al. 2009; Musezahl et al. 2009). Future endeavors to implement POU interventions will benefit from understanding the potential explanations for the successful promotion of boiling in Indonesia. First, government policy regarding water treatment has been clear and consistent for many decades. At all levels of the health system, boiling water was the only practice promoted to improve water quality. Second, the practice of boiling was considered to be easy. This perception could be a result of cultural norms established in Indonesian society in response to consistent messaging from the government. Third, the population indicated that the practice was inexpensive and practical. It appears that barriers of cost and inconvenience found with boiling in other countries were not appreciable in this setting where abundant and cheap fuel was readily available. Finally, a relatively high percentage of respondents indicated that boiling killed germs, which suggests

| Table 2 | Water sources among study households, South Sulawesi, March–November 2007 |
|-----------------------------------------------|-----------------|-----------------|-----------------|
| Characteristics of main water source | Bantaeng, % (*n* = 127) | Maros, % (*n* = 115) | Total, % (*n* = 242) |
| Improved | 93 | 87 | 90 |
| Piped (not municipal) | 73 | 69 | 71 |
| Public tap | 13 | 3 | 8 |
| Well water protected | 2 | 11 | 7 |
| Pump well water | 2 | 3 | 2 |
| Piped (municipal) | 2 | 0 | 1 |
| Spring water protected | 1 | 2 | 1 |
| Unimproved | 6 | 13 | 9 |
| Well water unprotected | 4 | 7 | 5 |
| Surface water | 2 | 1 | 1 |
| Spring water unprotected | 0 | 3 | 1 |
| Rain water | 0 | 1 | <1 |
| Refilled water | 0 | 1 | <1 |
| Other | 2 | 1 | 2 |

households that reported boiling. Analysis of paired water samples for each household based on reported boiling of water samples demonstrated a 0.4 (95% CI = 0.0–0.9) log₁₀ reduction among households that reported not boiling versus a 1.9 (95% CI = 1.7–2.1) log₁₀ reduction among households that did boil.

The prevalence of contamination with *E. coli* in stored water was greater in wide-mouthed storage containers than narrow-mouthed storage containers (PR = 1.4, 95% CI = 1.1–1.8), in uncovered storage containers than covered storage containers (PR = 1.8, CI = 1.3–2.5), and in storage containers belonging to respondents who were observed to touch the water while collecting or serving it than in those where respondents did not touch the water (PR = 1.6, 95% CI = 1.3–2.1). Households in Bantaeng were more likely than Maros households to have stored water contaminated with *E. coli* (PR = 1.4, CI = 1.0–2.0). Respondents with less than an elementary school education had a greater tendency to have stored water contaminated with *E. coli* than more educated respondents (PR = 1.3, 95% CI = 1.0–1.6). There was no significant difference in prevalence of contaminated stored water by wealth quintile.

A multivariable model, controlling for district, education, container type and observation of respondents touching water, showed that stored water contamination was independently associated with not boiling (model-adjusted PR = 1.9, CI = 1.5–2.3).
that awareness of health benefits of boiling were understood. Interestingly, this finding was in contrast to the perception by most that their water was ‘clean’. It is possible that the perception of clean had more to do with physical appearance (i.e. clarity) than belief in the safety of water.

Despite the apparent achievement of scale and a measure of effectiveness in improving water quality through boiling, a degree of caution is warranted. Among households that reported boiling, 44% of stored water samples were contaminated by \textit{E. coli}. Water stored in wide-mouthed containers, in uncovered containers, and water observed to have been touched while being removed from containers was more likely to be contaminated with \textit{E. coli}. In addition, stored water in households with less educated respondents had a greater tendency to be contaminated with \textit{E. coli}. Probably because of limited power, multivariate analysis was unable to distinguish between these factors, yet water storage and handling behaviors and education are likely to be interrelated in their role on water quality. Poorer and less educated populations have a greater burden of morbidity and mortality from diarrheal disease (Black \textit{et al.} 2003). Yet our study suggests that boiling promotion in South Sulawesi has been less effective in the groups that would most benefit from the intervention. This finding may help explain why

<table>
<thead>
<tr>
<th>Characteristics of water treatment</th>
<th>Bantaeng, (n = 127)</th>
<th>Maros, (n = 115)</th>
<th>Total, (n = 242)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treat water</td>
<td>81</td>
<td>97</td>
<td>88</td>
</tr>
<tr>
<td>(n = 103)</td>
<td>(n = 111)</td>
<td>(n = 214)</td>
<td></td>
</tr>
<tr>
<td>Main method</td>
<td>Boiling</td>
<td>100</td>
<td>97</td>
</tr>
<tr>
<td>Filter</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Reason for main activity</td>
<td>Kill germs</td>
<td>33</td>
<td>56</td>
</tr>
<tr>
<td>To be healthy</td>
<td>40</td>
<td>38</td>
<td>39</td>
</tr>
<tr>
<td>Safe</td>
<td>18</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Habit</td>
<td>8</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Easy</td>
<td>9</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Make water clean/sterile</td>
<td>7</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Perceived cost</td>
<td>Cheap</td>
<td>88</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>Expensive</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Boils water</td>
<td>81</td>
<td>95</td>
<td>88</td>
</tr>
<tr>
<td>(n = 103)</td>
<td>(n = 109)</td>
<td>(n = 212)</td>
<td></td>
</tr>
<tr>
<td>Perceived practicality</td>
<td>Practical</td>
<td>77</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Impractical</td>
<td>23</td>
<td>10</td>
</tr>
<tr>
<td>Perceived cost</td>
<td>Cheap</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Expensive</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Perceived difficulty</td>
<td>Easy</td>
<td>74</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>Neither easy nor difficult</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Difficult</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Drinks untreated water</td>
<td>19</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>(n = 24)</td>
<td>(n = 4)</td>
<td>(n = 28)</td>
<td></td>
</tr>
<tr>
<td>Reasons for not treating</td>
<td>Safe</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Habit</td>
<td>33</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Practical</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Fresher</td>
<td>13</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^{a}\)For some items, \(n\) may vary by a small number.
Indonesia, despite its successful promotion of boiling, is still afflicted with a large number of diarrheal deaths in children under 5 years old despite recent economic development (Black et al. 2010).

In addition to questions of reliability of boiling as a water quality intervention, other drawbacks to the practice have been documented. These include high cost in some settings (Gilman & Skillicorn 2013), high opportunity costs of finding fuel and boiling and cooling water, the risk of burns from cooking fires among young children in developing countries (Rossi et al. 1998; Uygur et al. 2009), indoor air pollution and acute respiratory infections (Smith 2002), the contribution of black soot from cooking fires to greenhouse gases (Jacobson 2001), and lack of residual protection against recontamination of water during storage (Mintz et al. 1995; Reiff et al. 1996; Quick et al. 1999). Maintaining cleanliness of boiled water has been shown to be particularly challenging in focally contaminated environments (Wright et al. 2007), and in post-disaster situations (Gupta et al. 2011). Finally, in some settings, particularly in sub-Saharan Africa (Rosa et al. 2010), boiling is infrequently practiced, suggesting that there may be significant barriers to its use.

There were several important limitations to our study. First, our evaluation population was limited to the pre-selected communities of the SWASH program in South...
Sulawesi. As such, these communities were not representative of Indonesia as a whole. Second, evaluation communities were located in rural, wooded areas with easy access to brush and trees for fuel which would facilitate the practice of boiling. The frequency and effectiveness of boiling may differ in populations without easy and free access to fuel. Third, we were unable to observe actual boiling practices, so we could not confirm treatment status. Finally, although we translated the surveys into the national language of Bahasa Indonesia, many respondents had other local dialects as their first language. Interpretation of differences between ethnic groups should consider the role of possible misinterpretation of the Bahasa Indonesia questions.

CONCLUSION

Of all POU water treatment methods, boiling is the oldest, the most common, and arguably the only one that has reached meaningful scale in the developing world. Several studies including this one have documented that populations in developing countries that boil drinking water have reduced bacterial indicators of fecal contamination. However, a significant proportion may not boil water effectively, the practice of which includes proper storage and water handling to avoid recontamination. Further research is needed to answer three important questions regarding water treatment. First, can populations that have adopted the habit of boiling be successfully trained at scale to boil effectively and store water safely in clean and narrow-mouthed containers to maximize the benefit? Second, if practiced properly, how does the cost, ease and effectiveness of boiling compare with those of other POU technologies, such as chlorination and filtration? Third, can other POU water treatment technologies that are cheaper, easier to use, and perhaps more effective than boiling be scaled up to the same degree as boiling? The answers to these questions will help determine the progress that can be made in making household water treatment an effective intervention to protect the health of vulnerable populations until the longer term goal of providing safe water supplies for all is achieved.

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