

FACTORS ASSOCIATED WITH *E. COLI* CONTAMINATION OF HOUSEHOLD DRINKING WATER AMONG TSUNAMI AND EARTHQUAKE SURVIVORS, INDONESIA

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Abstract. The December 2004 tsunami in Sumatra, Indonesia, destroyed drinking water infrastructure, placing over 500,000 displaced persons at increased risk of waterborne disease. In June 2005, we assessed the relationship of water handling behaviors to household water quality in three districts: Aceh Besar, Simeulue, and Nias. We surveyed 1,127 households from 21 communities and tested stored drinking water. Factors associated with a reduced likelihood of having contaminated stored drinking water included obtaining water from improved sources (Aceh Besar, adjusted odds ratio (aOR) 0.41, $P < 0.01$; Simeulue, aOR 0.48, $P = 0.02$), using chlorine solution (Simeulue, aOR 0.41, $P < 0.01$), and having free chlorine in stored water (Aceh Besar, aOR 0.42, $P < 0.01$; Nias, aOR 0.28, $P < 0.01$). Reported boiling, even among those who could describe correct practice, was not associated with improved water quality. Water source improvement and household water chlorination appear to be useful strategies to improve household stored drinking water quality in post-disaster situations.

INTRODUCTION

The earthquake and tsunami of December 26, 2004 and earthquake of March 28, 2005, in Aceh and North Sumatra provinces, Indonesia, caused over 128,000 deaths, 93,000 missing persons, and 500,000 internally displaced persons (IDPs).¹ The successive disasters destroyed water and sanitation infrastructure through physical disruption of municipal water systems as well as aquifers supplying springs and wells and contamination of wells with debris and salt water. As a result, large displaced populations may have been subject to an increased risk of waterborne disease. Health facility-based disease surveillance established by the government of Indonesia in collaboration with the World Health Organization showed that acute watery diarrhea was the second leading cause of morbidity, accounting for 23% of 40,706 consultations.² Recognizing the importance of early access to safe water, some relief organizations immediately supplied water in tanker trucks and procured bottled water, while others promoted boiling.³ Assessments in Aceh Province showed that water in some tanker trucks was contaminated beyond acceptable limits⁴ and that boiling was not effective.^{3,5}

An additional household water quality strategy, the Safe Water System (SWS),⁶ was promoted by CARE Indonesia after the tsunami, taking advantage of an existing program in Indonesia. The SWS, which consists of three elements—(1) household water treatment with locally produced sodium hypochlorite solution, (2) safe water storage in the home, and (3) behavior-change communications—has been shown to reduce the risk of diarrhea by 25–85%.^{7–11} SWS solution was distributed 3 days after the tsunami in Banda Aceh, the capital of Aceh province, and the surrounding district, Aceh Besar. After the March earthquake, SWS solution was distributed in the affected island districts of Simeulue, Aceh Prov-

ince, by CARE, and Nias, North Sumatra Province, by International Medical Corps (IMC). In June 2005, in response to requests from CARE and IMC, a team from the Centers for Disease Control and Prevention (CDC) evaluated factors associated with household drinking water quality in these areas.

MATERIALS AND METHODS

The evaluations took place in Aceh Besar, where persons lived in temporary tent camps and where they had moved into temporary living centers (TLCs) consisting of wooden barracks sheltering multiple households, and on Nias and Simeulue islands, which were accessible only by aircraft or boat and contained poorer populations living in villages. Simeulue was the only area severely affected by both the December and March disasters, and the traumatized population had moved away from their villages, fields, and beaches to makeshift houses on hilltops.

We used a two-stage sampling approach in each of four population strata. For the first stage, we used lists, prepared by CARE and IMC, of all 83 accessible communities where SWS had been implemented, to randomly choose 21 communities with probability proportional to the number of households. The number of communities surveyed was limited by resource constraints. We selected 6 of 16 TLCs and 5 of 15 tent camps in Aceh Besar; 5 of 35 villages in Hiliduhu sub-district of Nias; and 5 of 17 villages in Teupah Salatan sub-district of Simeulue. For the second stage, we selected a systematic random sample of households from each of these communities (lists of households were not available for Nias and Simeulue, so maps drawn in consultation with village leaders were used instead). We chose a sample size for households estimated to be sufficient to detect an SWS utilization rate of 30%, with a margin of error of $\pm 10\%$. We did not attempt to identify a head of household because many families had been disrupted.

Ten locally hired interviewers administered a questionnaire in the local language to an adult present in the household at

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the time of the survey. The instrument included questions and observations regarding demographics and water, hygiene, and sanitation practices. Drinking water stored in the home was tested for residual free chlorine using a calibrated digital chlorimeter (Chlorine Free and Total Single Test Colorimeters, LaMotte Co., Chestertown, MD) and for the presence or absence of *Escherichia coli* using the Colilert® (Idexx Laboratories, Inc., Westbrook, ME) method.¹² Water was collected directly into specimen bottles to obtain water samples similar to those ingested by respondents.

Questionnaire and laboratory data were analyzed using SAS 9.1 software (SAS Institute, Cary, NC). Complex survey design-based analysis, generalized estimating equations, and generalized linear mixed models were used to determine associations between various interventions and water quality and were compared to examine the robustness of model description.

This project was reviewed by the Associate Director of Science, National Center for Infectious Diseases, CDC, and was determined to be a program evaluation of public health practice, for which Institutional Review Board regulations did not apply. Informed consent was obtained from all respondents, however, and personal identifiers were irretrievably removed from all databases.

RESULTS

We interviewed persons from 653 (7.8%) of 8,292 households where SWS had been implemented in Aceh Besar, 206 (3.6%) of 5,658 in Nias, and 268 (13.1%) of 2,052 in Simeulue. Unless indicated, the following frequencies have been adjusted, incorporating the multistage cluster design, to represent the entire population where the SWS had been implemented.

More than 50% of responding individuals in each of the three districts were female and were married. Household size was at least five persons in 38% of households in Aceh Besar, 77% in Nias, and 58% in Simeulue. In Aceh Besar, 39% of persons had not completed junior high school compared with 57% in both Nias and Simeulue.

Water sources were categorized as improved (boreholes and rainwater) or unimproved (surface water and unprotected wells or springs) based on WHO/UNICEF Joint Monitoring Program for Water Supply and Sanitation classifications.¹³ All wells and springs in the communities sampled were not protected and were therefore classified as unimproved water sources. Although tanker truck water was

sometimes contaminated, it was less frequently contaminated than other sources and was sometimes chlorinated⁴ and was therefore considered improved for the purposes of this study. Over 70% of households in Nias and Simeulue relied on unimproved water sources compared with only 41% in Aceh Besar. Narrow-mouthed containers were used to store water in ≈ 60% of households in each district.

In Aceh Besar, 81% of persons reported treating water by any method, in contrast to 99% and 100% in Nias and Simeulue, respectively. The 118 persons in Aceh Besar who reported not treating their water obtained their drinking water from tanker trucks (52%), springs (22%), open wells (8%), bottled water (7%), tubewells (7%), the municipal water system (3%), and surface sources (1%). Over 90% of persons in Simeulue and Nias reported boiling, compared with 58% in Aceh Besar. Adequate boiling practice, defined as achieving a rolling boil for at least 1 minute, was reported by 90% in Simeulue but only by 48% in Aceh Besar and 34% in Nias. Reported use of SWS solution was 28% in Aceh Besar, 21% in Nias, and 12% in Simeulue. Of those reporting SWS use, adequate levels of chlorine, defined as at least 0.1 mg/L, were present in 50% of households in Aceh Besar, 70% in Nias, and 22% in Simeulue.

In all three areas, > 60% of persons were observed using soap while washing their hands. The proportion of individuals who said they used a latrine varied considerably by area, with 82% in Aceh Besar, 54% in Nias, and only 13% in Simeulue.

Household stored water samples were frequently contaminated with *E. coli* in all three evaluation sites: 124 (20%) of 620 samples in Aceh Besar, 38 (24%) of 162 in Nias, and 118 (48%) of 244 in Simeulue (Table 1).

The likelihood of detecting *E. coli* was less in stored water obtained from improved water sources than from unimproved sources in Aceh Besar (14% versus 29%, adjusted odds ratio (aOR) 0.40, 95% confidence interval [CI]: 0.21 to 0.75) and Simeulue (34% versus 52%, aOR 0.48, 95% CI: 0.26 to 0.88), and a similar trend was noted in Nias (14% versus 27%, aOR 0.43, 95% CI: 0.13 to 1.47). The remainder of the analysis was adjusted for type of water source: improved or unimproved.

Using a narrow-mouthed container was not found to be associated with clean stored water (Table 2). Similarly, reported boiling was not found to be associated with a decreased risk of contaminated stored drinking water in any of the three areas (Aceh Besar, 22% versus 19%, aOR 1.32, 95% CI: 0.95 to 1.84; Nias, 24% versus 13%, aOR 1.73, 95% CI: 0.26 to 11.64; Simeulue, 47% versus 42%, aOR 1.27, 95% CI: 0.51 to 3.14). Neither adequate boiling (maintaining a

TABLE 1

Number and percent of stored water samples positive for *E. coli* among survey respondents by source, Aceh and North Sumatra, Indonesia, June–July, 2005

	Percent (number contaminated/total)			
	Aceh Besar	Nias	Simeulue	Total
Borehole	14 (14/100)	0	0	14 (14/100)
Rainwater	0	14 (6/43)	35 (19/55)	26 (25/98)
Tanker trucks	14 (41/285)	0	0	14 (41/285)
Well	30 (40/133)	30 (18/61)	51 (66/130)	38 (124/324)
Spring	28 (21/76)	22 (11/51)	45 (13/29)	29 (45/156)
Surface water	100 (1/1)	43 (3/7)	66 (19/29)	62 (23/37)
Other (bottled, municipal)	28 (7/25)	0	100 (1/1)	31 (8/26)
Total	20 (124/620)	24 (38/162)	48 (118/244)	27 (280/1026)

TABLE 2

Univariate analysis of water, hygiene, and sanitation practices compared to *E. coli* contamination of household drinking water in SWS implementation areas, Aceh and North Sumatra, Indonesia, June–July, 2005

	Adjusted odds ratio (95% confidence interval)*		
	Aceh Besar	Nias	Simeulue
Improved water source	0.40 (0.21–0.75)	0.43 (0.13–1.47)	0.48 (0.26–0.88)
Any water treatment	0.87 (0.49–1.55)	0.50 (0.03–10.20)	All reported treating
Narrow-mouthed container	0.94 (0.56–1.59)	2.18 (0.54–8.80)	1.39 (0.86–2.25)
Boiling drinking water	1.32 (0.95–1.84)	1.73 (0.26–11.64)	1.27 (0.51–3.14)
Rolling boil for 1 minute	1.08 (0.74–1.58)	1.00 (0.27–3.75)	0.76 (0.25–2.33)
SWS use in stored water	0.52 (0.27–0.98)	0.95 (0.29–3.07)	0.46 (0.36–0.60)
Chlorine \geq 0.1 mg/L	0.42 (0.23–0.77)†	0.28 (0.16–0.51)§	0.38 (0.15–0.98)§
Observed soap use	0.82 (0.56–1.21)	1.35 (0.51–3.53)	0.62 (0.44–0.86)
Latrine use	0.60 (0.33–1.09)	0.82 (0.38–1.79)	0.40 (0.28–0.55)

* Adjusted for water source: improved or unimproved.

† Includes chlorine from SWS solution as well as tanker trucks.

§ Includes SWS solution only, as no tanker trucks were used in these communities.

rolling boil for at least one minute) nor adequate boiling combined with water storage in a narrow-mouthed container was associated with a decreased risk of stored water contamination.

In contrast, reported use of chlorine solution in stored water was associated with having clean drinking water in Aceh Besar (14% versus 23%, aOR 0.52, 95% CI: 0.27 to 0.98) and Simeulue (33% versus 49%, aOR 0.46, 95% CI: 0.36 to 0.60) but not in Nias (21% versus 25%, aOR 0.95, 95% CI: 0.29 to 3.07). Having residual free chlorine in stored water of at least 0.1 mg/L was associated with a reduced risk of *E. coli* contamination of stored water in all three areas (Aceh Besar, 11% versus 24%, aOR 0.42, 95% CI: 0.23 to 0.77; Nias, 9% versus 28%, aOR 0.28, 95% CI: 0.16 to 0.51; Simeulue, 29% versus 48%, aOR 0.38, 95% CI: 0.15 to 0.98). SWS solution was the only source of chlorine in drinking water in Nias and Simeulue, while tanker trucks were a second potential source in Aceh Besar; however, results were similar although not statistically significant after excluding households in Aceh Besar that received tanker truck water (reported chlorine solution use: aOR 0.53, 95% CI: 0.24 to 1.18; \geq 0.1 mg/L free chlorine: aOR 0.45, 95% CI: 0.18 to 1.14).

In Simeulue, both observed use of soap while washing hands (43% versus 56%, aOR 0.62, 95% CI: 0.44 to 0.86) and use of a latrine (27% versus 49%, aOR 0.40, 95% CI: 0.28 to 0.55) were associated with less drinking water contamination.

Multivariable models were constructed for Aceh Besar, Nias, and Simeulue (Table 3). All variables found to be significantly associated with contamination of stored water in univariate analysis were included in the models (Table 2). However, for Simeulue, the variables were not independent, and only three variables could be fitted in any given model; the model with the highest likelihood ratio is presented. Households using improved water sources were less likely to have contaminated drinking water in Aceh Besar (aOR 0.41, $P < 0.01$) and Simeulue (aOR 0.48, $P = 0.02$). Similarly, households using SWS in stored water in Simeulue (aOR 0.41, $P < 0.01$) and households having at least 0.1 mg/L of free chlorine in stored water in Aceh Besar (aOR 0.42, $P < 0.01$) and Nias (aOR 0.28, $P < 0.01$) were less likely to have contaminated drinking water. Households with a latrine were also less likely to have contaminated drinking water in Simeulue (aOR 0.35, $P < 0.01$). Also in Simeulue, all 10 alternative multivariable models that included observed use of soap to wash hands showed it to be independently associated with

less risk of contaminated drinking water (aOR range 0.59 to 0.65, $P \leq 0.01$).

DISCUSSION

Five months after intensive post-tsunami efforts to guarantee the provision of safe water in Aceh, Indonesia, chlorination of stored water either in tankers or at the household level was the only practice that was associated with a reduced risk of *E. coli* in drinking water in all three evaluation sites. The apparent efficacy of point of use chlorination is consistent with findings of other studies.^{7–9,14–16}

Despite this finding, a relatively low percentage of stored water samples had detectable chlorine residuals even though the chlorine solution had been distributed free of charge. This result was consistent with the observation that achieving high uptake has been a challenge in general for household water-treatment strategies. In this situation, there were several possible reasons for the low level of detectable chlorine residuals. First, in Simeulue, where chlorine usage was lowest and the need was greatest, SWS promotion was not optimal because the program had begun shortly before the study and staff training had not been completed. Second, water was reportedly more turbid in Simeulue than in Aceh Besar or Nias and may have had a higher chlorine demand, resulting in undetectable chlorine residuals in stored water; however, this supposition could not be confirmed as turbidity measurements

TABLE 3

Predictors of *E. coli* contamination of household drinking water in SWS implementation areas from final multivariate models, Aceh and North Sumatra, Indonesia, June–July, 2005

	Adjusted odds ratio	95% Confidence limits	P value
Aceh Besar			
Improved water source	0.41	0.22, 0.76	< 0.01
SWS use in stored water	0.68	0.39, 1.18	0.17
Chlorine \geq 0.1 mg/L*	0.42	0.23, 0.77	< 0.01
Nias			
Chlorine \geq 0.1 mg/L†	0.28	0.16, 0.51	< 0.01
Simeulue			
Improved water source	0.48	0.26, 0.87	0.02
SWS use in stored water	0.41	0.29, 0.59	< 0.01
Using a latrine	0.35	0.24, 0.52	< 0.01

* Includes chlorine from SWS solution as well as tanker trucks.

† Includes SWS solution only, as no tanker trucks were used in these communities.

were not performed. Third, in Aceh Besar, almost half of respondents who reported that they did not treat their water used tanker truck water, possibly because some relief agencies communicated the message that tanker truck water was safe¹⁷ despite the finding that disinfection was inconsistent.⁴ Finally, some persons reported not liking the taste or smell of chlorinated water. Different implementation approaches, such as community mobilization,^{18,19} or strategies for increasing the sustainability of the SWS program could possibly help increase chlorination practices in the future.

In Aceh Besar and Simeulue, the use of improved water sources was also associated with a decreased risk of having contaminated stored water. Nevertheless, stored drinking water from improved sources was frequently contaminated with *E. coli*. In post-disaster situations, this problem could be mitigated by adequate water-quality monitoring, which could trigger protective actions.³ For example, if monitoring revealed source water contamination, either treatment of source water or promotion of point-of-use water treatment could be implemented. In the absence of any water-quality monitoring system, as occurred in the post-tsunami situation, household water-treatment technology could be promoted or provided to the population. In addition, to avoid further contamination of stored drinking water, it is also important to promote hand-washing with soap and safe disposal of feces.²⁰

Although boiling was the point of use water quality intervention promoted by most relief agencies after the tsunami, our findings showed that water reported to be boiled was no more likely to be free of contamination with *E. coli* than untreated water. This finding was consistent with three other evaluations conducted after the tsunami.³ Possible explanations for this finding include inadequate boiling procedures, improper water handling after boiling which permitted recontamination, or false reports of boiling. Investigation of these possible explanations is needed through further research. These results, however, point to the need for intensive education and adequate water-quality monitoring if boiling is to be recommended in such settings. These findings also cast doubt on a published assertion that the promotion of boiling had prevented outbreaks of diarrheal disease from occurring after the tsunami.²¹

Improved storage containers were found to be no more effective in protecting stored water from microbial contamination than wide-mouthed storage containers. This finding contrasts with a previous study that suggested that the use of improved storage containers could protect the quality of stored water from clean sources by preventing recontamination^{22,23} and other studies that showed that water storage in uncovered, wide-mouthed containers was associated with outbreaks of disease.^{24–27} This apparently anomalous finding could be explained by two factors. First, many water sources may not have been clean, and, in the case of respondents who did not report treating their water, contaminated water would have been placed in both improved or unimproved storage containers. The lack of a *qualitative* difference in the quality of water stored in the two types of containers would therefore not be surprising. At least one other study has documented similar findings.¹⁴ Second, there was no apparent association between the combination of reported or confirmed chlorination and use of improved storage containers on water quality, which suggests that improved storage containers did not add additional benefit to chlorination alone. This implies that

chlorine, rather than the type of container, was the more important barrier against recontamination of stored water.

This study was conducted in a post-disaster setting and had three substantial limitations. First, logistical limitations prevented the use of quantitative methods to measure *E. coli* in drinking water. Consequently, the study lacked data on the degree of source and stored drinking water contamination. It is unlikely, however, that quantitative microbiologic data would have substantially changed our conclusions. Second, due to resource constraints and a highly mobile population, we were unable to directly measure longitudinal diarrhea prevalence in the post-disaster environment. Third, although *E. coli* is the most accepted indicator of microbiological water quality, the relationship of the presence of *E. coli* to the risk of diarrheal disease is unknown, and may depend on multiple factors, such as the specific micro-organisms present.

Despite a massive international response to this disaster, at the end of the recovery phase³ stored household drinking water was frequently contaminated. This problem highlighted the difficulties in coordinating efforts and messages among multiple agencies responding to the tsunami.³ Stored drinking water obtained from improved water sources was frequently contaminated, boiling was widely promoted as the preferred method of water treatment but was not found to be effective, and household use of chlorine solution, though not promoted by most responding agencies, was widely distributed, proven effective, but used infrequently. These findings demonstrate the importance of using evidence-based interventions, periodic rapid impact assessments of those interventions, and coordination with partner organizations to provide the most effective solutions for disaster-affected populations. This evaluation also supported providing improved water supplies, sanitary facilities, and hygiene promotion, interventions that are fundamental to any disaster relief effort.

Received June 7, 2006. Accepted for publication December 5, 2006.

Acknowledgments: The authors acknowledge the research team for their assistance. We are grateful to project partners, which included the Government of Indonesia, United States Agency for International Development, Johns Hopkins University Center for Communications Programs, CARE International Indonesia, International Medical Corps, and UNICEF. We also thank Heather Van Sice, Bertha Butar Butar, Rustini Floranita, Gercelina Silaen, and Frank Tyler for logistical and technical support.

Financial support: This evaluation was financed and supported by CARE International Indonesia, with assistance from International Medical Corps.

Disclaimer: There are no relationships or support among any of the authors that might be perceived as constituting a conflict of interest.

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