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Effective Use of Household Water Treatment and Safe Storage in Response to the 2010 Haiti Earthquake

Daniele Lantagne* and Thomas Clasen

Department of Civil and Environmental Engineering, Tufts University, Medford, Massachusetts; Department of Disease Control, Faculty of Infectious and Tropical Diseases, London School of Hygiene and Tropical Medicine, London, United Kingdom

Abstract. When water supplies are compromised during an emergency, responders often recommend household water treatment and safe storage (HWTS) methods, such as boiling or chlorination. We evaluated the near- and longer-term impact of chlorine and filter products distributed shortly after the 2010 earthquake in Haiti. HWTS products were deemed as effective to use if they actually improved unsafe household drinking water to internationally accepted microbiological water quality standards. The acute emergency survey (442 households) was conducted within 8 weeks of emergency onset; the recovery survey (218 households) was conducted 10 months after onset. Effective use varied by HWTS product (from 8% to 63% of recipients in the acute phase and from 0% to 46% of recipients in the recovery phase). Higher rates of effective use were associated with programs that were underway in Haiti before the emergency, had a plan at initial distribution for program continuation, and distributed products with community health worker support and a safe storage container.

INTRODUCTION

On January 12, 2010, a 7.0 magnitude earthquake struck 17 km southwest of Port-au-Prince, Haiti. Nearly one-third of Haiti's population, almost 3 million people, was affected.[1] An estimated 222,517 people died, and 310,928 people were injured.[2] The United Nations Children's Fund (UNICEF)-led Water, Sanitation, and Hygiene (WASH) Emergency Cluster estimated that 1.1 million people displaced into 651 spontaneous settlements needed services.[2] Outmigration of an estimated 482,000 people from affected areas also strained resources in rural Haiti.[3]

Before the earthquake, numerous household water treatment and safe storage (HWTS) methods were promoted in Haiti to improve the microbiological quality of stored household drinking water and reduce diarrheal disease.[4] These methods included consumable products, such as chlorine tablets, liquid chlorine, and powdered chlorine sold in the markets or distributed by relief organizations, and durable products, such as imported ceramic and multibarrier filters and locally manufactured biosand filters. Boiling has not been widely promoted in Haiti because of extensive deforestation, and flocculant/disinfectant and locally made ceramic filter programs had been discontinued before the earthquake.[4] Overall, 45.6% of urban and 24.4% of rural populations in Haiti reported treating drinking water before the earthquake, and the large majority (42.0% and 21.2% of the overall population, respectively) treated water by adding bleach or other chlorine products.[5] Small percentages (0.1–3.4%) reported boiling, filtering, solar disinfection, settling and decanting, using commercial flocculant/disinfectants, adding citrus, and other approaches.

Evidence suggests that HWTS can improve household water quality and reduce diarrheal disease in the development context.[6,7] As a result, UNICEF and the World Health Organization (WHO) recommend HWTS as part of a comprehensive strategy to prevent diarrheal disease in low-income settings.[8]

Safe drinking water is also an immediate priority in most emergencies.[9] When normal water supplies are interrupted or compromised because of natural disasters, complex emergencies, or outbreaks, responders have often encouraged affected populations to boil or disinfect their drinking water to ensure its microbiological safety. Because of increased risk from waterborne disease, HWTS has been hypothesized to be an effective emergency response intervention in (1) flooding events or natural disasters that lead to displacement[10]; (2) complex emergency settings (such as Haiti) when relief does not always progress to development; and (3) outbreaks caused by untreated drinking water, especially cholera outbreaks.[11] HWTS may also be especially effective during the acute phase of an emergency when responders cannot yet reach the affected population with longer-term solutions.

However, differences between the emergency and development phases may affect HWTS effectiveness in emergencies. Emergencies have higher crude mortality rates[12] and likelihood of outbreaks because of population migration[13]; and, a higher level of funding affects what water and sanitation technologies are selected in emergencies.[14] Also, there are competing priorities for staff time in emergencies. These differences raise questions about the generalizability of HWTS results from development into emergency contexts. Most evidence to date has been on coverage rather than uptake or impact. There is some evidence that HWTS can be effective in improving water quality in small-scale, non-acute emergencies with a high-diarrheal disease risk when training and materials were provided to recipients, adequate product stocks were maintained, and chlorine dosage was appropriate.[15] However, there is little evidence on effectiveness during the acute emergency phase—within the first 8 weeks.

It is also possible that populations that adopt HWTS in response to an emergency may continue to follow the practice long term—because of increased awareness of HWTS methods, experience using the interventions, and improved access to HWTS methods—after the emergency. In one study, 48.7% of 115 recipient households visited had a working filter 16 months after ceramic filter distribution

*Address correspondence to Daniele Lantagne, Department of Civil and Environmental Engineering, Tufts University, 200 College Avenue, Room 207A, Medford, MA 02155. E-mail: daniele.lantagne@tufts.edu

in response to flooding in the Dominican Republic.[16] Another study conducted in Sri Lanka found that, 2 years after ceramic filters were distributed in response to the 2004 tsunami, 71% of households self-reported ceramic filter use that day or the day before.[17] Both studies, however, noted the importance and difficulty of establishing distribution mechanisms to provide or sell replacement parts to users.

In this paper, we report on the results of a study undertaken with support from UNICEF, Oxfam Great Britain, and Oxfam America to investigate the contribution of HWTS in the Haiti earthquake relief during both the acute emergency phase (weeks 3–8 after the earthquake) and the longer-term recovery phase (about 10 months later). We assessed this contribution by determining the extent to which affected households that were reportedly provided HWTS products actually used those products to improve drinking water quality and safety.

METHODS

Situational analysis: sampling strategy. On arrival in Haiti for the acute phase assessment, we determined the scope of HWTS product distributions by communicating with the UNICEF-led WASH Emergency Cluster coordinating the response, HWTS promoters, emergency responders, and HWTS product manufacturers. The objective was to determine which HWTS products were available in the country, which had actually been distributed to households, and which households had received the products. We then mapped the location and size of the populations targeted by responders who distributed HWTS products to develop an appropriate sampling frame for household surveys and water quality testing. In the acute emergency phase, households were selected for surveying using weighted random sampling stratified by responder and HWTS method. For the recovery phase, the same survey technology was used in programs with households that could still be located. Please note that the exact households were not revisited and that the survey randomizations were recompleted.

Household surveys. After receiving informed consent from the head of household, trained enumerators conducted household surveys using tools translated into Kreyol, back-translated, and pre-tested. The initial acute emergency survey was conducted between February 19 and March 11, 2010 and included questions on respondent and household characteristics, household assets, diarrhea prevalence, water knowledge, water source before and after the earthquake, water management practices, and type of HWTS product received. A second recovery survey was administered between October 29 and November 9, 2010, to households that had received HWTS products during the acute emergency phase.

Water testing. During the survey, enumerators tested household stored water for free chlorine residual (FCR) using a Hach ColorWheel (Loveland, CO) test kit at households reporting use of chlorine-based products or stored untreated tanker truck water. In accordance with WHO standards for effective disinfection, FCR $\geq$ 0.2 mg/L at the time of sampling was considered to be confirmed use.[18] In addition, in households that reported treated water on the day of the unannounced survey, treated and untreated water samples from the same source as the treated water were collected aseptically in sterile WhirlPak bags with sodium thiosulfate (Nasco, Ft. Atkinson, WI) and stored on ice for subsequent assay of total coliform and *Escherichia coli* using a Millipore (Billerica, MA) filtration stand and mColiBlue24 media (Millipore, Billerica, MA). Samples were diluted appropriately with sterile buffered water, filtered aseptically through a 45-micron filter (Millipore, Billerica, MA), placed in a plastic Petri dish with a media-soaked pad, and incubated for 24 hours at 35°C. Water sampling and analysis were designed to conform with Standard Methods, except that the holding time before analysis was at times extended up to 12 hours because of travel logistics.[19] Negative boiled water controls were included each day, and 10% of samples were duplicated. Turbidity was measured within 24 hours of collection with a Lamotte 2020 turbidimeter (Chestertown, MD) calibrated weekly with non-expired stock calibration solutions.

Effective use. Most emergency response evaluations are based solely on inputs (such as chlorine tablets delivered), coverage (such as number of people served), or reported use (such as households reporting HWTS product use). Although direct assessments of health impact are rarely possible in the critical early stages of an emergency, it is nevertheless important to target interventions to those people at risk and provide them with solutions to mitigate that risk. In this evaluation, we use the metric effective use[20] to capture the extent to which the HWTS method (1) reached a population at risk from waterborne disease and (2) was actually used by that population to reduce their risk. Effective use is, thus, the percent of targeted households with water that was microbiologically contaminated that used the intervention to improve their water quality to internationally accepted standards. The contaminated/uncontaminated breakpoint was calculated two ways: (1) if the untreated water had greater than 1 CFU/100 mL *E. coli* before treatment and less than 1 CFU/100 mL after treatment (WHO definition of safe water)[18] and (2) the same calculation but using the low-risk guideline value of < 10 CFU/100 mL as the breakpoint.[21] A secondary outcome variable for chlorine-based HWTS methods was the FCR level in household-treated water. We also measured turbidity in treated and untreated water samples, because reductions in turbidity have been associated with increased user acceptance of HWTS methods and improved microbiological outcomes.[22]

Data entry and analysis: ethics. All household survey and water quality data were entered into Microsoft Excel (Redmond, WA) and analyzed using Excel and Stata 10.1 (College Station, TX). For the purposes of this study, the WHO definition of improved water sources was modified to include tanker trunk water, because this context was an emergency context. Thus, in the results summary, the sources are referred to as protected (improved sources + tanker truck water) or unprotected (unimproved sources). Comparisons between groups in survey response data were calculated using the χ^2 test. *E. coli* results were analyzed by first computing the geometric mean (with *E. coli* values of 0.0 transformed to 0.5 for analysis) and then using *t* test of log-normalized data to compare groups. The study was approved by the Ethics Committee of the London School of Hygiene and Tropical Medicine. Participating householders voluntarily consented to participate in the study after receiving full details and an opportunity to ask questions.

RESULTS

Programs included. We identified and followed up with five programs that distributed HWTS methods within 8 weeks of emergency onset: (1) continuous community-based distribution of Aquatabs brand chlorine tablets and safe storage containers with training and oversight by 165 community health workers (CHWs) by the local pre-emergency non-governmental organization (NGO) Deep Springs International (DSI) to 2,880 families in rural and urban areas of Leogane; (2) non-food item (NFI) kit distribution of Aquatabs chlorine tablets with no training by the international NGO Haiti Response Coalition (HRC) to an unknown number of families in 48 spontaneous settlements in Port-au-Prince; (3) distribution of ceramic filters with one training by local NGO FilterPure to approximately 350 families near Jacmel; (4) distribution of biosand filters with one training by local pre-existing NGO Clean Water for Haiti (CWH) to 238 families associated with churches across Port-au-Prince; and (5) distribution of 70 bottles of Klorfasil chlorine powder to groups of five families in one spontaneous settlement by international NGO Klorfasil. There was no geographical overlap in these programs. The numbers of households included in the study for each responding organization and technology are shown in Table 1. Klorfasil program results are not presented herein because of the small program and hence, small sample size. Overall, these five projects included 4,618 households (an estimated 23,090 individuals) that received HWTS products during the acute emergency phase in Haiti. Of these five programs, only the DSI Aquatabs/safe storage container distribution and CWH biosand filter programs were underway in Haiti before the emergency, with the others entering as part of the earthquake response. Additionally, only DSI reported that it had a pre-established plan to transition from providing free Aquatabs to selling locally manufactured sodium hypochlorite in refillable bottles as the emergency progressed to recovery. The HRC Aquatabs program in spontaneous settlements was not included in the recovery evaluation, because the households could not be located because of migration.

Household surveys. Study population characteristics by program in the acute and recovery phases are presented in Tables 1 and 2, respectively. Overall, 363 households were surveyed in four programs in the acute phase (range per program = 43–182), and 218 households were surveyed in three programs in the recovery phase (range per program = 28–143). The study populations covered by each survey were similar in most respects. Most respondents had attended school and were literate. Most respondents in the initial survey reported migrating during the 8 weeks after the earthquake, whereas most in the recovery survey respondents did not. At least two-thirds of households in each program stored water in their homes, mainly with covers and in buckets. Most households reported access to protected water supplies.

Reported HWTS use during acute phase. In the acute emergency phase, respondents generally reported current use of HWTS products that they received in the emergency response (Table 1). These reports included 86% of households reporting use in the DSI program (using Aquatabs primarily, with a few households reporting using the locally generated liquid chlorine brand Gadyen Dlo), 24% reporting use in the HRC program (primarily Aquatabs and some with other chlorine), 72% reporting use in FilterPure households

Table 1
Study population characteristics in the acute emergency evaluation

	DSI Aquatabs/bucket (Leogane)	HRC Aquatabs (PaP)	FilterPure ceramic filters (Jacmel)	CWH Biosand filters (PaP)
Number of households surveyed	182	87	43	51
Number (%) of FRs (N = 362)	125 (69)	56 (64)	22 (52)	21 (41)
Average respondent age in years (minimum to maximum; N = 363)	38.6 (15–75)	25.5 (7–70)	36.6 (17–69)	42.4 (19–78)
Number (%) of FRs who attended school (N = 224)	95 (76)	46 (82)	16 (73)	20 (95)
If FR attended school, average (minimum to maximum) years (N = 177)	9.2 (1–19)	9.3 (2–18)	8.3 (1–15)	11.8 (4–20)
All FR average (minimum to maximum) years of school (N = 224)	6.9 (0–19)	7.6 (0–18)	6.0 (0–15)	11.2 (0–20)
Number (%) female HOHs who can read the newspaper (N = 363)	129 (73)	68 (82)	26 (65)	41 (87)
Number (%) moved within 8 weeks after the earthquake (N = 356)	115 (65)	84 (97)	7 (17)	38 (78)
Number (%) with no household stored water (N = 363)	1 (1)	29 (33)	5 (12)	10 (20)
Number (%) with covered stored water (N = 315)	178 (99)	57 (98)	36 (100)	40 (98)
Number (%) using buckets (N = 315)	161 (91)	28 (48)	27 (71)	32 (78)
Number (%) using unprotected sources (N = 310)	84 (47)	1 (2)	4 (10)	6 (15)
Number (%) reporting receiving Aquatabs for free (N = 363)	169 (93)	83 (95)	0 (0)	0 (0)
Number (%) reporting any treatment (N = 363)	157 (86)	21 (24)	31 (72)	27 (53)
Number (%) reporting water treated with Aquatabs	152 (84)	19 (22)	0 (0)	0 (0)
Number (%) reporting water treated with Gadyen Dlo	5 (3)	0 (0)	0 (0)	0 (0)
Number (%) reporting water treated with other chlorine	0 (0)	2 (2.3)	0 (0)	0 (0)
Number (%) reporting water treated with filter	0 (0)	0 (0)	31 (72)	27 (53)
Number (%) reporting water treated with filter and chlorine	0 (0)	0 (0)	0 (0)	0 (0)
Number (%) reporting water treated with boiling	0 (0)	0 (0)	0 (0)	0 (0)
Number (%) reporting water treated with PuR	0 (0)	0 (0)	0 (0)	0 (0)
Number (%) reporting untreated water	25 (14)	66 (76)	12 (28)	24 (47)
Number (%) chlorine-treated water with ≥ 0.2 mg/L FCR (N = 363)				
Reported Aquatabs-treated water	131 (72)	13 (15)	0 (0)	0 (0)
Reported Gadyen Dlo-treated water	5 (3)	0 (0)	0 (0)	0 (0)
Reported other chlorine-treated water	0 (0)	2 (2)	0 (0)	0 (0)
Reported filter- + chlorine-treated water	0 (0)	0 (0)	0 (0)	0
Correct knowledge of Aquatabs use (N = 249)	126 (75)	43 (53)	–	–

FR = female respondent; HOH = head of household.

Table 2
Study population characteristics in the recovery evaluation

	DSI chlorine/ bucket (Leogane)	FiltePure Ceramic filters (Jacmel)	CWH Biosand filters (PaP)
Number of households surveyed	143	28	47
Number (%) FRs (N = 218)	121 (85)	25 (89)	33 (70)
Average respondent age in years (minimum to maximum; N = 215)	40.0 (17–84)	36.1 (18–62)	38.6 (20–60)
Number (%) of FRs who attended school (N = 179)	88 (73)	20 (80)	31 (94)
If FR attended school, average (minimum to maximum) years (N = 137)	9.5 (2–22)	10.4 (2–16)	11.8 (3–21)
All FR average (minimum to maximum) years of school (N = 177)	6.8 (0–22)	8.3 (0–16)	11.1 (0–21)
Number (%) of female HOHs who can read the newspaper (N = 179)	82 (68)	19 (76)	29 (88)
Number (%) moved after 8 weeks after the earthquake (N = 217)	48 (34)	9 (32)	10 (21)
Number (%) with no household stored water (N = 218)	15 (10)	4 (14)	4 (9)
Number (%) with covered stored water (N = 191)	127 (100)	22 (96)	39 (95)
Number (%) using buckets with spigots (N = 209)	128 (92)	10 (37)	3 (7)
Number (%) using unprotected sources (N = 193)	50 (39)	3 (13)	1 (2)
Number (%) reporting receiving Aquatabs for free (N = 218)	138 (97)	11 (39)	10 (21)
Number (%) reporting any treatment (N = 218)	116 (81)	17 (61)	34 (72)
Number (%) reporting water treated with Aquatabs	74 (52)	5 (18)	9 (19)
Number (%) reporting water treated with Gadyen Dlo	37 (26)	0 (0)	0 (0)
Number (%) reporting water treated with other chlorine	3 (2)	1 (4)	4 (9)
Number (%) reporting water treated with filter	0 (0)	7 (25)	11 (23)
Number (%) reporting water treated with filter and chlorine	0 (0)	2 (7)	10 (22)
Number (%) reporting water treated with boiling	1 (0.7)	2 (7)	0 (0)
Number (%) reporting water treated with PuR	1 (0.7)	0 (0)	0 (0)
Number (%) reporting untreated water	27 (19)	11 (39)	13 (28)
Number (%) reporting water treatment with purchased chlorine (N = 218)	–	6 (21)	21 (45)
Number (%) chlorine-treated water with ≥ 0.2 mg/L FCR (N = 218)	103 (90)	3 (43)	17 (74)
Reported Aquatabs-treated water (N = 87)	68/74 (92)	2/4 (50)	6/9 (67)
Reported Gadyen Dlo-treated water (N = 37)	32/37 (86)	–	–
Reported other chlorine-treated water (N = 8)	3/3 (100)	0/1 (0)	3/4 (75)
Reported filter- and chlorine-treated water (N = 12)	–	1/2 (50)	8/10 (80)
Correct knowledge of Aquatabs use (N = 156)	111 (82)	4 (36)	4 (40)

FR = female respondent; HOH = head of household.

(ceramic filters), and 53% reporting use in the CWH program (biosand filters) (Table 1). Reported use was confirmed in chlorine-based products with an FCR ≥ 0.2 mg/L in 75% of all DSI respondents and 15% of all HRC respondents. Respondents reported discontinued use of the biosand filters because sand flowed out with treated water. On visual inspection, it was noted that the biosand filters were installed incorrectly, with no standing water layer.

Reported HWTS use in recovery phase. In the recovery phase, HWTS use was more varied (Table 2). Overall, 81% of DSI respondents reported current water treatment in stored household water: 52% with Aquatabs and 26% with Gadyen Dlo (Table 2). FCR ≥ 0.2 mg/L was present in the vast majority (86–92%) of households reporting chlorine treatment. Because the intention of the DSI program was to transition to cost recovery based on sales of Gadyen Dlo, households were asked a number of questions related to purchase of Gadyen Dlo. We found that 71% of respondents in the DSI program knew where to purchase Gadyen Dlo, 30% reported ever purchasing the product, and 47% had a bottle in their home at the time of the survey (some of whom received the bottle for free). Of those respondents with a bottle, 80% had sodium hypochlorite in the bottle. The main reasons for purchasing Gadyen Dlo (N = 41) were it cleans water (80%), prevents disease (39%), and is here (5%). The main reasons for not purchasing Gadyen Dlo (N = 48) were I have free Aquatabs (50%), I do not have money to buy (33%), and I prefer Aquatabs (21%). Of note is that 97% of respondents in the DSI program had continued to receive free Aquatabs from organizations distributing tablets in response to the earthquake and subsequent cholera outbreak and hurricane preparation in October of 2010. Thus, at the time of this evaluation, sales of Gadyen Dlo did not support the cost recovery continuation of the program (M. Ritter, personal communication).

Of 28 respondents who had received a ceramic filter, 7 (25%) reported having ceramic filter-treated water in the recovery phase, and another 2 (7%) reported treating water with chlorine after ceramic filtration (Table 2). Another 18% reported treating their water with Aquatabs, 4% reported using local chlorine, and 7% reported treating by boiling. Of 47 respondents who had received a biosand filter, 11 (23%) reported having water treated with biosand filters in the recovery phase, and another 10 (22%) reported treating water with chlorine after biosand filtration. Another 19% reported Aquatabs-treated water, and 9% reported using local chlorine. As seen in the DSI program, filter households reported receiving free Aquatabs, increasing from 0% during the acute phase to 21–39% in the recovery phase. These free Aquatabs distributions impacted water treatment practices, because 7–22% of households with filters reported not just filtering their water but filtering and chlorinating their water, which was not reported as a practice in the acute emergency evaluation. The main reason for ceramic filter disuse was filter broke (47%, 7 of 13 respondents), and the main reason for biosand filter disuse was filter broke and too much time (15% each, 3 of 20 respondents). Lastly, 29% of urban households and 4% of rural households in the DSI program reported ever buying Aquatabs compared with 45% in the biosand filter program and 16% in the ceramic filter program. Correct knowledge of Aquatabs use was higher in the DSI program (82%) than the filter programs (36–40%), and concurrently, confirmed FCR ≥ 0.2 mg/L was also higher in DSI program respondents (90%) compared with CWH and FilterPure program respondents (43–74%).

Water turbidity. Water turbidity was low across all untreated drinking water sources in both the acute emergency and recovery evaluations, confirming the suitability of chlorine-based products without prior filtration or flocculation. The average turbidity of 299 samples tested of 316 untreated stored water samples collected in the acute evaluation was 1.7 NTU (minimum = 0.0, maximum = 33). Only 10 (3.3%) samples were > 10 NTU, indicating the need for double chlorine dosage, filtration before disinfection, or more frequent cleaning of filters.[23] The average turbidity of 155 untreated water samples tested in the recovery evaluation was 3.8 NTU (minimum = 0, maximum = 46), with only 15 (9.7%) samples > 10 NTU.

Water quality. Untreated stored household water samples were collected from 316 (71.5%) of the total 442 surveyed households in the acute emergency phase and 155 (71.1%) of 218 surveyed households in the recovery phase. Samples were not collected, because there was no stored household water, there was only treated water in the household, or rarely, the enumerator did not collect/the household did not provide untreated water. Samples were categorized as (1) no stored untreated water, (2) untreated water from protected sources (community source, closed well, capped spring, or rainwater catchment), (3) untreated water from unprotected sources (open well, river, or unprotected spring), and (4) tanker/purchased water (tanker truck, bladder, sachet, or bottled water). In the acute phase, DSI Aquatabs safe storage recipients used the highest percentage of unprotected sources, and FilterPure ceramic filter recipients used the highest percentage of protected sources (Figure 1). In the recovery evaluation, DSI recipients remained the largest users of unprotected sources, although a higher percentage of DSI recipients reported using protected sources than in the acute evaluation. Biosand filter recipients reported the least use of unprotected sources in the recovery evaluation.

In the acute emergency phase, *E. coli* contamination was found in untreated stored household water from 70 (71%) of 99 protected sources, 30 (81%) of 37 unprotected sources, and 14 (56%) of 25 tanker truck waters tested (Table 3). *E. coli* contamination in protected sources, including tanker truck waters for this context, was significantly lower ($P < 0.001$) than in unprotected sources; 14 tanker truck samples with *E. coli* contamination ranged from 14 to 1,000 col/100 mL,

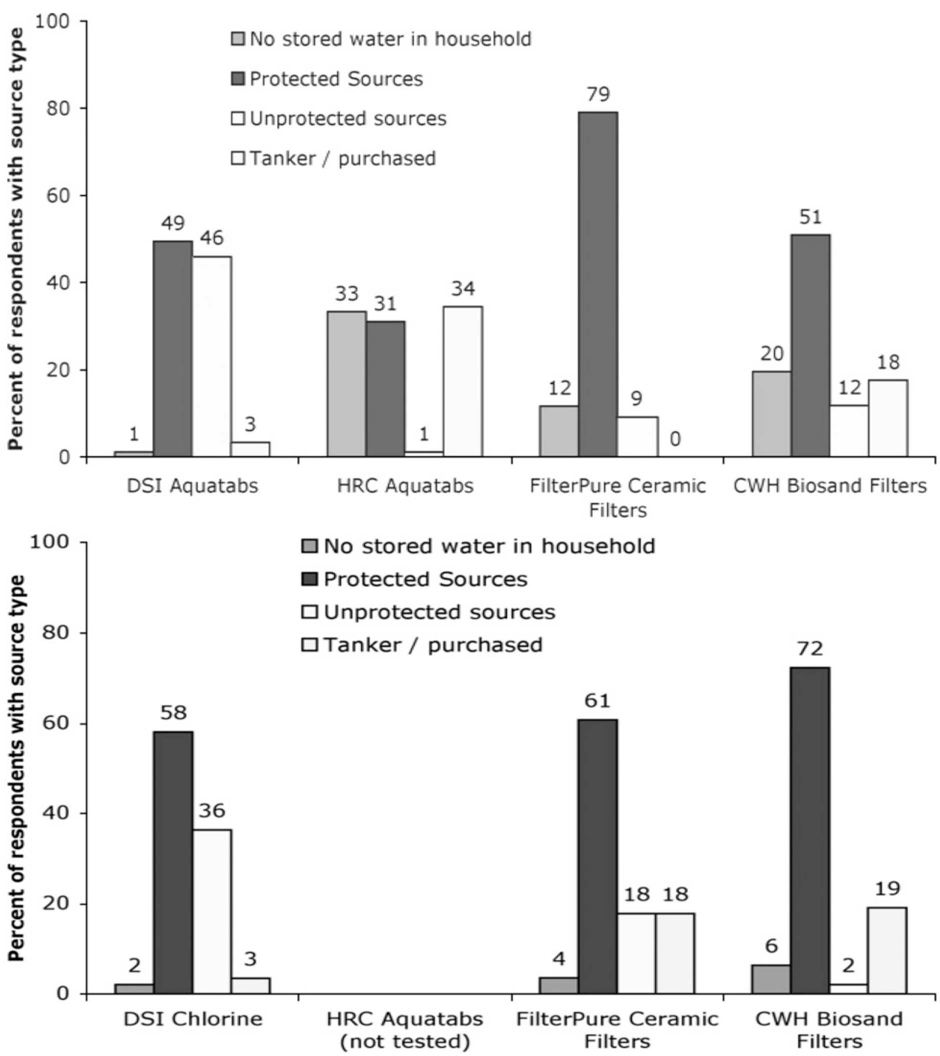

FIGURE 1. Untreated stored household water source by implementation program in (upper) acute and (lower) recovery phases.

Table 3
E. coli results by program and source type

	Acute emergency phase evaluation*		Recovery phase evaluation	
	E. coli (CFU/100 mL) GM (95% CI) *n*; untreated water	*E. coli* (CFU/100 mL) GM (95% CI) *n*; treated water	*E. coli* (CFU/100 mL) GM (95% CI) *n*; untreated water	*E. coli* (CFU/100 mL) GM (95% CI) *n*; treated water
Program				
DSI Aquatabs Safe Storage Program	28.1 (15.4–51.4) *N* = 59	0.74 (0.54–0.99) *N* = 59	10.9 (6.08–19.4) *N* = 93	0.64 (0.52–0.79) *N* = 103
HRC Aquatabs Program	20.8 (8.8–49.6) *N* = 25†	1.90 (0.44–8.15) *N* = 15	–	–
FilterPure Ceramic Filter Program	2.6 (0.1.7–7.9) *N* = 29	0.76 (0.51–1.12) *N* = 29	2.48 (0.71–8.61) *N* = 21	0.76 (0.51–1.14) *N* = 15
CWH Biosand Filter Program	93.4 (25.6–341.2) *N* = 21	8.49 (2.35–30.7) *N* = 19	3.88 (0.58–26.0) *N* = 15	1.40 (0.38–5.17) *N* = 15
Source type†				
Unprotected	51.3 (19.9–132.5) *N* = 37	0.92 (0.52–1.63) *N* = 36	28.5 (10.8–75.0) *N* = 42	0.91 (0.54–1.53) *N* = 43
Protected (including tanker)	11.4 (7.6–17.1) *N* = 124	1.38 (0.94–2.02) *N* = 108	4.00 (2.29–6.98) *N* = 87	0.64 (0.52–0.78) *N* = 90

CI = confidence interval; GM, geometric mean.
*Please note that, during the acute emergency phase evaluation, there were two additional programs sampled that are not presented because of small sample size. Therefore, the number of samples by source type (including all six programs) is larger than the number of samples by program (including only four programs).
†The sample size difference is because of sampling of some untreated samples without a matched treated pair.

and FCR was 0 mg/L in 17 (77%) of 22 untreated tanker truck water samples. When stratified by program, *E. coli* contamination in DSI program untreated samples was significantly higher (P = 0.016) than in unprotected sources from the other programs combined.

When treated water samples were stratified by program in the acute emergency phase, *E. coli* contamination in the DSI Aquatabs safe storage program-treated samples was significantly lower (P = 0.005) than treated water samples from all other programs combined. However, a statistically significant difference was not seen (P = 0.168) between protected and unprotected source waters after treatment.

In the recovery phase, *E. coli* contamination was found in untreated stored household water from 39 (45%) of 87 protected sources and 31 (74%) of 42 unprotected sources (Table 3). *E. coli* contamination in protected sources was significantly lower ($P < 0.001$) than unprotected sources. When stratified by program, *E. coli* contamination in DSI program untreated samples was still significantly higher (P = 0.012) than unprotected sources from the other two programs combined.

When treated water samples were stratified by program in the recovery phase, *E. coli* contamination in DSI-treated samples was significantly lower (P = 0.037) than treated water samples from all other programs combined. However, a statistically significant difference was not seen (P = 0.068) between protected and unprotected source waters after treatment.

Effective use. In the acute emergency phase, paired (treated/untreated) water samples were analyzed for microbiological contamination from 143 households to determine the level of effective use (Table 4). Overall, the highest effective use in the acute phase evaluation was seen in rural areas of DSI Aquatabs safe storage programs, with an effective use rate of 67.5% compared with rates of 8.4–20% in other programs (Table 4). In the recovery phase evaluation, results were slightly less, with 46% of DSI Aquatabs/Gadyen Dlo recipients with effective use compared with 0–28% in other programs. Results were similar using the < 10 CFU/100 mL and the < 1 CFU/100 mL breakpoints. It should be noted that these calculations for the filters rely on small sample sizes in the recovery evaluation because of difficulty finding households that had received and were continuing to use these filters.

DISCUSSION

We identified five programs that included distribution of HWTS products in response to the Haiti earthquake. According to the implementers, these programs reached a total of 4,618 households or an estimated 23,090 people (0.77% of the affected population). Based on these coverage figures alone, HWTS had little potential to make a significant contribution to those people impacted by the emergency. By contrast, for example, tanker truck water distributions reached 870,000 people or about 37 times more people during the same period.[2]

These coverage results are consistent with qualitative data obtained after the 2004 Indian Ocean tsunami.[24] Investigators found that, with the possible exception of boiling, HWTS did not play a significant role in the acute phase of the emergency response. As in Haiti, tanker truck water played a leading role, because most responders found that providing HWTS was not a suitable intervention. However, the *E. coli* contamination results seen in tanker truck water

Table 4
Effective use by program

	Acute emergency phase evaluation		Recovery phase evaluation	
	Effective use (< 1 CFU/100 mL; %, *n*)*	Effective use (< 10 CFU/100 mL; %, *n*)	Effective use (< 1 CFU/100 mL; %, *n*)	Effective use (< 10 CFU/100 mL; %, *n*)
DSI Aquatabs Safe Storage Program	63 (58; 68% rural, 57% urban)	49 (58; 53% rural, 44% urban)	46 (77; 51% rural, 37% urban)	41 (77; 44% rural, 32% urban)
HRC Aquatabs Program	13 (13)	10 (13)	–	–
FilterPure Ceramic Filter Program	20 (29)	12 (29)	0 (6)	11 (6)
CWH Biosand Filter Program	8 (19)	20 (19)	28 (6)	18 (6)

*Please note that *n* is the number of treated to untreated pairs tested for *E. coli*. The number of pairs moving from contaminated to uncontaminated is multiplied by the reported use to calculate the effective use.

presented herein highlight the need for adequate FCR to maintain the safety of tanker truck water supplies.

Although the number of households actually reached by implementers of HWTS was fairly modest compared with those people affected, most of the targeted households actually had the HWTS products in their possession and reported using them. There were also high levels of knowledge regarding the correct use of the product.

The potential for a water quality intervention to reduce risk may best be measured by assessing the extent to which it reaches households that are relying on contaminated water supplies and use the intervention to render their water safe for drinking—a metric that we term effective use. The potential for the HWTS products to actually reduce waterborne disease risk in Haiti was limited by the fact that many recipient households relied on improved water supplies, including in this study, tanker water. Although these water supplies are not necessarily free of microbiological contamination, our results show that they are significantly less contaminated than non-improved sources.

Some programs did achieve higher levels of effective use than others. The characteristics of more successful programs were (1) they targeted households with contaminated water, such as those households using unimproved sources, (2) they provided an HWTS method that effectively treated the water, and (3) they provided the product a population familiar with the product and willing to use it along with training in its use with the necessary supplies, including a safe storage container. When these factors came together, such as in the DSI program, high effective use was observed. When one factor was missing—such as lack of contaminated water in the ceramic filter distribution, where the majority of recipients used protected water supplies; a working product in the biosand filter distribution, where biosand filters were incorrectly installed; or, sufficient training and follow-up in the Aquatabs distribution in spontaneous settlements—effective use dropped considerably. It is of note that, in all programs, the initial water turbidity was appropriate for the HWTS methods distributed.

The real challenge in the continuing relief-to-recovery Haiti earthquake response, particularly as the cholera epidemic that began in October of 2010 continues and hurricane season recurs, is to create sustained and affordable access to safe drinking water. As tanker truck supplies phase out, alternatives, such as improved water supplies, kiosk water, and HWTS, will be appropriate for different segments of the affected population. In the recovery evaluation, compared with the acute emergency evaluation, a higher percentage of surveyed households had access to improved sources and had stored household water, and households reported less migration. This increased access to improved sources (and hence, clean untreated water) did contribute, along with a slight 5% drop in reported use from 86% to 81% of HWTS products, to a decrease from 63% to 46% in effective use in the DSI program from the acute to recovery situation. These results indicate a return to normalcy in the 10 months after the earthquake and indicate the potential for longer-term sustained use of HWTS methods. The results from this study can inform currently ongoing cholera response activities distributing HWTS products.

However, sustained effective use was not maintained in all programs during the recovery phase. The majority of HWTS programs initiated in the acute emergency phase had no plans to continue beyond immediate emergency response. In the recovery phase, ceramic filters were technologically sound and used at a respectable rate but were installed in households with little microbiological contamination and over time, they broke; biosand filters were not technologically sound and little used because of maintenance problems. The chlorine options distributed by DSI were technologically sound items distributed to a population without safe water with CHW mobilization, and thus, fairly high use was observed, even at recovery. This high use is consistent with other studies of HWTS implementations with CHW promotion.[25,26] However, the plan by DSI to transition from free distribution of Aquatabs to cost recovery distribution of Gadyen Dlo was not successful in achieving program cost recovery because of, in part, the advent of new emergencies, such as the cholera epidemic and hurricane season, and subsequent substantial free distribution of Aquatabs.

It is of interest to note that similar acute emergency and recovery evaluations were conducted in Turkana, Kenya, where the Kenya Red Cross Society distributed Aquatabs and PuR with one training to populations affected by cholera and flooding.[27] In this evaluation, no use in the recovery phase was seen, because there was no supply chain for the consumable products distributed; thus, the affected population lost access to the products. Combined recommendations from these two evaluations in the recovery phase were made for organizations interesting in creating sustained use of HWTS products in the post-emergency period.[27] These recommendations include to (1) develop a strategy for recovery at program outset; (2) ensure continued access (market-based or free distribution) after the emergency; (3) distribute chlorine technologies and safe storage in the acute phase and follow-up with durable technologies, boiling, or chlorination if the emergency proceeds to recovery, depending on what is appropriate for the local circumstances; (4) target HWTS to populations with long-term access to only unimproved water sources and concurrently consider the development of improved water sources; (5) provide training and follow-up to the families that is appropriate for the HWTS technology distributed; and (6) provide safe storage containers to the population.

This work was limited by the challenges of working in the acute emergency and recovery phases and the timing of the multiple emergencies that occurred in Haiti. The cross-sectional study design allowed for calculation of risk reduction at only two points in the emergency, and no health outcomes were collected. Although effective use is a useful proxy for health outcomes, we acknowledge its shortcomings, because it does not investigate other transmission pathways or reduction of other fecal–oral pathogens. We do note that, if a technology does not effectively reduce *E. coli*, it is not likely to reduce other fecal–oral pathogens. Lastly, we only investigated programs initiated in the acute emergency phase, and thus, the recovery evaluation did not investigate programs that started after March 9, 2010.

Currently, the Haitian National Directorate for Safe Water and Sanitation (DINEPA) is developing a National Strategy for HWTS in Haiti. Lessons learned from this work and other evaluations will be incorporated into this strategy to assist in developing national guidelines for appropriate implementation of HWTS in response to natural disasters, cholera outbreaks, and the ongoing relief-to-recovery phase of the earthquake and cholera outbreaks. Additional research to provide information on how best to implement sustainable HWTS programs in Haiti and other complex emergency contexts is indicated until such time as piped, treated infrastructure water can be provided to the entire population.

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Authors' addresses: Daniele Lantagne, Department of Civil and Environmental Engineering, Tufts University, Medford, MA, E-mail: daniele.lantagne@tufts.edu. Thomas Clasen, Environmental Hygiene Group, London School of Hygiene and Tropical Medicine, London, United Kingdom, E-mail: thomas.clasen@lshtm.ac.uk.

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