Point-of-use water treatment in emergency response

DANIELE LANTAGNE and THOMAS CLASEN

Point-of-use water treatment (PoUWT), such as boiling or chlorine disinfection, has long been recommended in emergencies. While there is increasing evidence that these and other PoUWT options improve household water microbiological quality and reduce diarrhoeal disease in the development context, it is unknown whether these results are generalizable to emergencies. The authors conducted a literature review and survey of implementers, and found that PoUWT was effective in small-scale, non-acute, high diarrhoeal disease-risk emergencies when training and materials were provided to recipients, adequate stocks were maintained, and chlorine dosage was appropriate. There was little documented effectiveness in acute emergencies, with untested products, or during large-scale distributions without training. Results were incorporated into the Sphere Revision, which recommends selecting culturally acceptable PoUWT options, providing adequate products and training to recipients, pre-placing PoUWT products in emergency-prone areas, and using locally available products if continued use in the post-emergency phase is desired.

Keywords: emergencies, household water treatment, implementation; point-of-use water treatment

An estimated 4 billion cases of diarrhoea each year, causing 1.8 million deaths mainly among children under five years of age, are caused by unsafe drinking water, poor sanitation, and poor hygiene (Boschi-Pinto et al., 2008). Environmental health interventions to reduce this disease burden include: improved water sources, point-of-use water treatment (PoUWT), handwashing promotion, and sanitation (Esrey et al., 1985, 1991; Fewtrell et al., 2005). Five PoUWT options – chlorination, flocculant/disinfectant powder, solar disinfection, ceramic filtration, and biosand filtration – have been shown in the

Daniele Lantagne (email daniele.lantagne@lshtm.ac.uk) is an environmental engineer who has worked in over 40 countries providing technical assistance on household water treatment. She completed this work as a PhD candidate and research assistant at the London School of Hygiene and Tropical Medicine (LSHTM), working with her advisor Dr Thomas Clasen under a contract from CDC and USAID. Thomas Clasen is a Senior Lecturer in Water, Sanitation and Health at the LSHTM.

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development context to improve household water microbial quality and reduce diarrhoeal disease in users (Fewtrell and Colford, 2005; Clasen et al., 2007; Arnold and Colford, 2007), and another, boiling, is widely promoted. Based on this evidence, the World Health Organization (WHO) promotes PoUWT as one option to provide safe drinking water for the 884 million without access to improved water supplies and the millions more drinking microbiologically unsafe water from improved sources (WHO, 2008; UNICEF/WHO, 2008). While there is currently active debate in the water and sanitation community as to the most appropriate role for PoUWT options in development contexts that enables sustainable, consistent use over time, there remains consensus that PoUWT can improve microbiological quality of water and reduce disease in specific circumstances (Sobsey et al., 2008; Schmidt and Cairncross, 2009).

Safe drinking water is also an immediate priority in most emergencies (Sphere, 2004). When normal water supplies are interrupted or compromised following natural disasters, complex emergencies, or outbreaks, responders have often encouraged affected populations to boil or disinfect their drinking water to ensure its microbiological integrity. The Sphere Handbook provides international guidance for organizations conducting emergency response (Sphere, 2004), and recommends a minimum provision of 15 litres of water/person/day. As the emergency progresses from relief to development, the response shifts to providing higher-quality services such as long-term access to protected water supplies (Lantagne, 2009). Recently, PoUWT options verified in the development context have been recommended by numerous organizations for use in all stages of emergency response.

Options verified in the development context have been recommended for use in emergency response

PoUWT, as an intervention that reduces the diarrhoeal disease burden, could potentially be an effective emergency response intervention: 1) in response to emergencies with increased risk of diarrhoeal disease, including flooding events or natural disasters that lead to displacement (Noji, 1997); 2) in some complex emergency settings when relief cannot progress to development; and 3) in response to outbreaks caused by untreated drinking water, especially cholera outbreaks, which are currently increasing in severity and quantity throughout Africa (Gaffga et al., 2007). PoUWT may also be especially effective during the initial phase of an emergency when responders cannot yet reach the affected population with longer-term solutions.

PoUWT may be especially effective during the initial phase

However, differences between the emergency and development contexts may affect PoUWT effectiveness, including: 1) higher crude mortality rates (Toole and Waldman, 1990) and likelihood of outbreaks due to population migration (Watson et al., 2007) in emergencies; 2) a higher level of funding affecting what water and sanitation options are selected in emergencies (de Ville de Goyet, 2000); and 3) competing priorities for staff time in emergencies (CARE, undated).

These differences raise questions about generalizability of PoUWT results from development into emergency situations. This study was conducted to explore the evidence on PoUWT in emergencies, the extent and circumstances in which emergency responders currently implement the intervention, and lessons learned to date.

Methods

Literature review

Literature on PoUWT in emergencies was identified by conducting database searches on Ovid MedLine and PubMed using the following search terms: ((‘disaster*’ or ‘natural disaster*’ or ‘complex emergenc*’ or ‘emergenc*’ or ‘cholera’ or ‘outbreak’) and (‘household water treatment’ or ‘point of use’ or ‘point-of-use’ or ‘water treatment’)). We also contacted manufacturers, UN organizations, researchers, and programme implementers (including survey respondents) to obtain grey and unpublished literature.

Survey

Data was collected from implementers of PoUWT projects in emergencies using a Word Form survey distributed via email. The survey included a mixture of attribute, belief, and knowledge questions to gain information on survey respondents and their perspective and experiences. The survey began with open-ended questions about PoUWT in emergencies generally, and continued with forced-choice questions for each individual project (each using one or more PoUWT options) implemented by the responder.

A list of 307 email addresses of individuals involved in water or emergency response from UN organizations, development and emergency-focused non-governmental organizations, research institutions, and manufacturers was created based on the literature review, email lists from the Water, Sanitation, and Hygiene in Emergencies Cluster coordinated by UNICEF, and the authors’ personal contacts. The survey was emailed to this list on 29 May 2008. Recipients were encouraged to forward the survey to others able to supply information on PoUWT in emergency response. In addition, targeted emails were sent to additional identified individuals. Responses were accepted until 30 September 2008. Data collected was analysed by: 1) respondent, with answers to open-ended questions; 2) project, with answers to forced-choice questions; and 3) projects where only one PoUWT option was implemented, to compare between individual PoUWT options. The survey was approved by the LSHTM Ethics Committee.

Results

Literature review

Execution of the search strategy yielded a total of 28 journal articles, project evaluations, and manuals that met inclusion criteria of describing PoUWT interventions in emergencies (Table 1). By PoUWT method, this included nine (32.1 per cent) on the Procter & Gamble flocculant/disinfection product PuR, seven (25.0 per cent) on sodium hypochlorite (the CDC Safe Water System, SWS), four (14.3 per cent) on ceramic filtration, three (10.7 per cent) on boiling and safe storage promotion, three (10.7 per cent) on the 2004 Asian Tsunami specifically, one (3.6 per cent) on solar disinfection, and one (3.6 per cent) on a commercial filter. Although chlorine tablet distribution and bucket chlorination are common in emergencies (WHO, 2005), and biosand filtration is a common development intervention, no evaluations were identified using these options, although two of the PuR studies also investigated chlorine tablet distribution. Literature deemed of greater methodological quality is summarized herein categorized by PoUWT option. Effectiveness is measured by diarrhoeal disease reduction, microbiological indicator reduction, and user acceptance.

PuR

PuR was shown to effectively reduce diarrhoeal disease in a randomized, controlled intervention trial

PuR is the only PoUWT option shown to effectively reduce diarrhoeal disease in an emergency in a randomized, controlled intervention trial. In this trial, conducted during the rainy season, 400 households in two Liberian refugee camps were provided with a bucket, mixing spoon, decanting cloth, funnel, safe storage container, and 21 sachets of PuR per week (Doocy and Burnham, 2006). Materials that were stolen during the course of the intervention were promptly replaced. The primary caretaker received an initial training, which included a demonstration of the correct use of PuR, distribution of pictorial instruction materials, and a requirement to demonstrate they could correctly use PuR. Weekly active diarrhoeal disease surveillance and water quality testing occurred in intervention and matched control households (provided with a safe storage container only) for 12 weeks following training. Households using PuR reported 91 per cent less diarrhoeal incidence than control households, and diarrhoea prevalence was reduced by 83 per cent compared with baseline data. A compliance rate of 95 per cent was measured, verified by weekly chlorine residual testing. The mean free chlorine residual level was 1.6 mg/L. Respondents reported appreciating the visual improvement and taste of the treated water, and the observed diarrhoeal disease reduction.

Households using PuR reported 91% less diarrhoeal incidence than control households

Table 1. Journal articles, programme evaluations, and manuals identified describing PoUWT interventions in emergencies

PoUWT option	*Emergency type*	*Country*	*Methods*	*Outcome metrics*	*Source*
PuR	Refugee camp	Liberia	RCT, WQ testing	Diarrhoea, FRC	(Doocy and Burnham, 2006)
PuR	Refugee camp	Uganda	Project evaluation	Families collecting PuR	(SP, 2006)
PuR	Flooding	Haiti	Survey	Knowledge, FRC	(CARE, undated, Colindres et al., 2007)
PuR	Feeding programme	Ethiopia	Survey, WQ testing	FRC	(CARE, undated)
PuR	Complex	DRC	Survey	Knowledge	(IMC, 2008)
PuR/chlorine tablets	Flooding	Bangladesh	Survey, WQ testing	FRC, uptake, diarrhoea	(Hoque and Khanam, undated)
PuR/chlorine tablets	Flooding	Bangladesh	Survey, WQ testing	FRC, uptake, diarrhoea	(Johnston, 2008)
PuR	Seasonal flooding	Vietnam	Survey, WQ testing	FRC, uptake	(Handzel and Bamrah, 2006; UNICEF, 2007)
PuR	–	–	Manual	–	(Aquaya, 2005)
Sodium hypochlorite	Flooding/cholera	Madagascar	Survey, WQ testing	FRC, uptake	(Dunston et al., 2001)
Sodium hypochlorite	Cholera	Madagascar	Case-control	Cholera risk	(Reller et al., 2001)
Sodium hypochlorite	Flooding	Madagascar	Survey, WQ testing	FRC, uptake	(Mong et al., 2001)
Sodium hypochlorite/ boiling	Tsunami	Indonesia	Survey, WQ testing	FRC, *E. coli*, uptake	(Gupta et al., 2007)
Sodium hypochlorite	Complex	Haiti	Survey, WQ testing	Diarrhoea, FRC	(Brin, 2003)
Sodium hypochlorite	Complex	Haiti	Survey, WQ testing	FRC, uptake	(Ritter, 2007)
Sodium hypochlorite	–	–	Manual	–	(CDC, 2008)
Ceramic filtration	Tsunami	Sri Lanka	Survey	Uptake, use	(Palmer, 2005)
Ceramic filtration	Flooding	Dominican Rep.	RCT Survey, WQ testing	Faecal coliform Uptake, correct use	(Clasen and Boisson, 2006)
Ceramic filtration	Flooding	Haiti	Survey	Uptake, WTP	(Caens, 2005)
Ceramic filtration	–	Multiple	Filter factory evaluation	Best practices	(Lantagne, 2006)
Safe storage	Refugee camp	Sudan	Clinic record review	Diarrhoea	(Walden et al., 2005)
Safe storage/mother solution	Refugee camp	Malawi	RCT, WQ testing	Diarrhoea, faecal coli-form	(Roberts et al., 2001)
Boiling	Flooding	USA	Survey	Knowledge	(Ram et al., 2007)
SODIS	Cholera	Kenya	Sub-group of RCT	Diarrhoea	(Conroy et al., 2001)
Multiple interventions	Tsunami	India, Sri Lanka, Indonesia	Interviews, site visit	Evaluation	(Clasen and Smith, 2005)
Multiple interventions	Tsunami	Indonesia	WQ testing	WQ testing	(Gupta and Quick, 2006)
Multiple interventions	–	–	Manual	–	(WHO, 2005)
Nerox filter	IDP camp	Pakistan	Survey	Uptake	(Zehri and Ensink, 2008)

Note: FRC (free residual chlorine), WQ (water quality), RCT (randomized, controlled trial), WTP (willingness to pay)

Although five other PuR evaluations collected diarrhoeal disease data, only one collected controlled data, and none reported statistical significance. Other outcome metrics used for PuR emergency projects included: 1) an increase in families collecting their PuR ration from 69 per cent to 96 per cent over the 21-week intervention period in Uganda (SP, 2006); 2) 78 per cent of interviewed households correctly stating how to use PuR and 10 per cent having chlorine residual in household water in Haiti after flooding (Colindres et al., 2007); and 3) 95 per cent of interviewed families having chlorine residual in household water during seasonal flooding in Vietnam (Handzel and Bamrah, 2006; UNICEF, 2007).

Two of the richest PuR evaluations were conducted in Bangladesh after floods

Two of the richest PuR evaluations were conducted in Bangladesh after flooding events. In the first project evaluated, 20 PuR sachets and 20 Aquatabs were included in the relief packages for 4,800 families in 67 flood-affected villages in Bangladesh from September 2006 to February 2007 (Hoque and Khanam, undated). All recipients received group demonstration at distribution, and a subset of recipients received follow-up community level trainings conducted by project motivators. To assess the project, 239 families were visited to obtain 200 (83.7 per cent) families that were using one of the products at the unannounced household visit. Of the 200 families surveyed, 200 (100 per cent) had received PuR and 176 (88.0 per cent) had received Aquatabs. Three-quarters (150) were using PuR that day, with 50 (25 per cent) using Aquatabs. Water quality testing showed that no treated water sample had detectible faecal coliform, and all samples had free chlorine residual. The second evaluation was conducted after Cyclone Sidr in 2007 (Johnston, 2008). At least 5 million Aquatabs were widely distributed without specific training for recipients, and 120,000 PuR sachets were distributed with training. No faecal coliforms were detected in water treated with Aquatabs or PuR, and a greater number of households were using and preferred PuR to Aquatabs. A total of 100 per cent of households had PuR in the house, with 72 per cent having treated water at the time of the unannounced visit. A smaller percentage, 65 per cent of households, had Aquatabs in the house, with 10 per cent having treated water at the time of the unannounced visit.

In most of the PuR emergency project evaluations community health workers could reliably access families

All PuR in emergency project evaluations, except after flooding in Haiti, occurred in stable emergencies where community health workers could access families reliably over time. In Uganda, Ethiopia, and Vietnam, projects distributed one sachet/day/family, which was determined sufficient for most families' drinking water needs. In Liberia, Uganda, Ethiopia, Bangladesh, and DRC, buckets or buckets with stirring rods and cloth were distributed along with sachets. In Vietnam, households had the materials needed to use PuR because they were accustomed to using alum for flocculation.

Group demonstrations and weekly follow-up generated high uptake in Liberia, Bangladesh, and Vietnam, with 95.4 per cent, 62.8–72 per cent, and 95 per cent, respectively, of respondents having chlorine residual in household water. In Bangladesh, uptake of PuR was higher in households receiving centralized training and community follow-up (89 per cent) than in communities receiving only centralized training (54 per cent). In Haiti, where only community trainings were conducted, 10 per cent of recipients had chlorine residual in household water. Local registration was noted necessary for project implementation in Haiti and Vietnam.

In Liberia, respondents reported appreciating the taste, in Haiti 97 per cent of people reported PuR-treated water tasted better than non-treated water, and in Ethiopia taste was acceptable. In contrast, taste was a barrier in Bangladesh, and in Vietnam it was postulated people disliked the taste so intensely they boiled water after PuR treatment.

PuR willingness to pay ranged from: 1) an average 2.7 US cents (USC) in Haiti; 2) 44.5 per cent of respondents stating 0.4 USC in Bangladesh; and 3) 80 per cent of respondents in Vietnam stating 1.3–3.2 USC.

Chlorine tablets

The only chlorine tablet research identified was conducted concurrently with the Bangladesh PuR studies referenced above (Handzel and Bamrah, 2006; UNICEF, 2007; Hoque and Khanam, undated). In the two studies, 88 per cent and 65 per cent of PuR study households also received Aquatabs, and 25 per cent and 10 per cent, respectively, were using Aquatabs at the household visit. Aquatabs training was not provided, although PuR training was. All Aquatabs-treated household water had adequate chlorine residual and no faecal coliforms. Respondents preferred PuR ($p<0.001$), but were willing to use Aquatabs; and 30.5 per cent were willing to pay 0.4 USC per tablet.

Sodium hypochlorite

> All hypochlorite research identified in emergencies used in-country produced SWS development products

All hypochlorite research identified in emergencies used in-country produced SWS development products, which have been implemented in response to natural disasters, complex emergencies, and outbreaks.

Five months after receiving a cyclone relief kit containing sodium hypochlorite and foldable jerry cans, 25 per cent of recipients in Madagascar had chlorine residual in household water (Mong et al., 2001). Recipients were willing to pay US$0.38 for additional hypochlorite bottles. In addition, confirmed chlorine residual presence was 14 per cent, 14.7 per cent, and 2.64 per cent five months after the tsunami in three villages receiving free product during the emergency (Gupta et al., 2007). Factors associated with decreased risk of *E. coli* contamination in household water included: 1) reported sodium hypochlorite use; 2) chlorine residual presence; 3) observed use of washing hands with soap; and 4) latrine use. During the 2008 cyclone, PSI/Myanmar distributed enough locally made sodium hypochlorite to treat over 200 million litres of water; however, the efficacy of the intervention is unknown as no evaluation was conducted.

In the complex emergency of northern Haiti, sodium hypochlorite is locally produced. Families purchase hypochlorite for $0.10/month in refillable bottles, and technicians paid from programme income produce and sell the hypochlorite, train new users, and conduct household visits with existing users. After a 2003 evaluation documented significant reductions in microbiological contamination in users' household water (Brin, 2003), the project expanded, and in 2007, 67 per cent of programme households had chlorine residual in household water (Ritter, 2007). During disasters, project staff work with local churches and resellers to distribute tickets for free solution to affected families (Gallo, 2008).

During cholera outbreaks in Madagascar, documented usage (measured by chlorine residual in household water) was 11.2–19.7 per cent of households receiving community-based mobilization (Dunston et al., 2001). During one particular 2001 outbreak, sodium hypochlorite use (odds ratio = 0.1, 95%CI = 0.0–1.2) and boiling (odds ratio = 0.4, CI = 0.1–1.1) were associated with statistically insignificant reductions (p = 0.11 and 0.09, respectively, and attributed to small sample size) in cholera risk (Reller et al., 2001).

Ceramic filters

Evaluations of ceramic filter distributions in emergencies have been conducted in three locations

Evaluations of ceramic filter distributions in emergencies have been conducted in three locations. The first, in Sri Lanka after the 2004 tsunami (Palmer, 2005), found that the factors associated with use included: having used wells for drinking water before the tsunami, future planned well use, practising any type of water treatment, a greater length of time between the tsunami and filter distribution, higher quality of shelter, more programmatic support, and distribution of pot (instead of candle) filters. Barriers to use were insufficient filter training and lack of living space.

In a randomized, controlled trial, faecal coliform was found to be consistently lower among households using ceramic candle filters

Ceramic candle filters were also distributed to families affected by flooding in the Dominican Republic in 2003 (Clasen and Boisson, 2006). Community mobilizers identified and trained recipient families, who were advised the candles were effective for six months. Local businesses sold replacement filters for ~$4.50. In a randomized, controlled trial among 80 households, faecal coliform was found to be consistently lower among intervention than control households ($p<0.0001$). A cross-sectional study 16 months after filter distribution found 102 (88.7 per cent) recipient households still had their filters, 68 (66.7 per cent) were using them, 56 (48.7 per cent) filters were operating properly, and 30 (29.4 per cent) families had treated water free of faecal coliforms. Thirty-three (58.9 per cent) of the 56 households with an operating filter had replaced the filter.

In Haiti, ceramic filter systems were distributed after flooding in 2003 (Caens, 2005). Although users self-reported liking the filter and health benefits, willingness to pay for the filter was less than filter replacement costs, and area kiosks were not willing to stock the filter.

Standard emergency response interventions

Traditional PoUWT interventions include: boiling, safe storage promotion, and mother solution (on-site-produced sodium hypochlorite)

Three studies were identified investigating the standard and more traditional PoUWT emergency response interventions: boiling, safe storage promotion, and mother solution (on-site-produced sodium hypochlorite). In the previously referenced study after the tsunami, narrow-mouthed water storage container use, reported boiling, adequate boiling, and adequate boiling with water storage were not associated with decreased risk of *E. coli* in stored water (Gupta et al., 2007).

During an outbreak of shigellosis in a refugee camp in Sudan (Walden et al., 2005), a campaign involving house-to-house visits to clean their safe storage containers and distribute information was conducted. Although gathering statistically rigorous data was not possible, clinic health records showed a reduction of watery and bloody diarrhoea in the weeks following the cleaning project.

In a Malawian refugee camp, intervention households were provided with 1–3 improved 20-litre buckets with a lid and spout (Roberts et al., 2001). Mean faecal coliform counts were 53.3 per cent lower in improved buckets compared with normal buckets, and children in improved bucket households had a statistically insignificant 31.1 per cent reduction of diarrhoeal disease ($p=0.06$). Mother solution distributed by a health committee member in the camp was 27 per cent and 8 per cent of the required concentration in two tests.

Emerging technologies

Emerging PoUWT technologies such as microfilter gravity systems have been implemented in emergencies

Emerging PoUWT technologies – such as one microfilter gravity system that had been tested for microbiological efficacy, but undergone little field testing – have been implemented in emergencies (Zehri and Ensink, 2008). In Pakistan internally displaced camps, nine months after filter distribution, 21 (10 per cent) householders reported they used the filter every day, and on visual inspection, 12 (5.7 per cent) of the filters were in working condition. Users reported that water takes too long to filter (78 per cent), cleaning is difficult (23 per cent), the filter needs to be cleaned too often (24 per cent), and water becomes too hot (82 per cent).

Specific case: 2005 tsunami

The most thorough evaluation of PoUWT in a single emergency commenced eight weeks after the 2004 tsunami in India, Sri Lanka, and Indonesia (Clasen and Smith, 2005). Despite wide availability of products, PoUWT 'did not play a significant role in the initial phases of the tsunami response with the possible exception of boiling'. Boiling was widely promoted because it 'was well-known and widely accepted, it did not require programmatic support for its promotion, thus allowing them [NGOs] to focus on providing basic water and sanitation needs'.

Millions of PuR sachets, chlorine tablets, and sodium hypochlorite bottles were not used in the immediate aftermath of the tsunami

Millions of PuR sachets, chlorine tablets, and sodium hypochlorite bottles were not used in the immediate aftermath of the tsunami because: 1) water quantity was considered more important than water quality; 2) PoUWT was unnecessary because water was supplied from tanker trucks; 3) the scale of the emergency precluded human and other resource availability for PoUWT programmatic support; and 4) implementers were concerned about sending mixed messages diluting boiling promotion effectiveness and about promoting unsustainable PoUWT options.

In contrast to PoUWT options, water distribution options, such as water tankering, were widely used

In contrast to PoUWT options, water distribution options, such as water tankering, were widely used. In Aceh after the tsunami, 33 (44 per cent) tanker truck water samples had <0.1 mg/L chlorine residual, and 9 (17 per cent) tested positive for *E. coli* (Gupta and Quick, 2006). Factors leading to contamination included: 1) long wait times at filling stations causing drivers to fill trucks from untreated sources; 2) underchlorinated filling station water; and 3) sediment from untreated sources in tanker trucks exerting chlorine demand.

Survey results

Fifty-four respondents returned the email survey, with a response rate of 4.2 per cent (13) from the initial email, 1.9 per cent (6) from traceable email forwards, and 100 per cent (3) from targeted emails. It is unknown how 32 (59.3 per cent) respondents obtained the survey. Fourteen (26 per cent) responses were excluded from analysis because: they did not use PoUWT in an emergency (3); survey form was incomplete (1); and there were duplicate survey responses from resellers of one PoUWT option (11). The 40 remaining respondents included: 15 (37.5 per cent) from international development organizations; 17 (42.5 per cent) from international emergency organizations; 5 (12.8 per cent) researchers; 2 (5.1 per cent) manufacturers;

and 1 (2.6 per cent) individual. Respondents described projects using 19 PoUWT options (Figure 1). The nine other PoUWT options in the figure included: mission filter, alum, mother solution, locally made flocculant/disinfectant (2), chulli filter, UV, and SteriPen (2).

The 40 respondents described 77 projects using one or more PoUWT options (average 1.93 projects/respondent, range 1–8). Two projects were duplicates, and the survey response from the implementer was included in subsequent analysis.

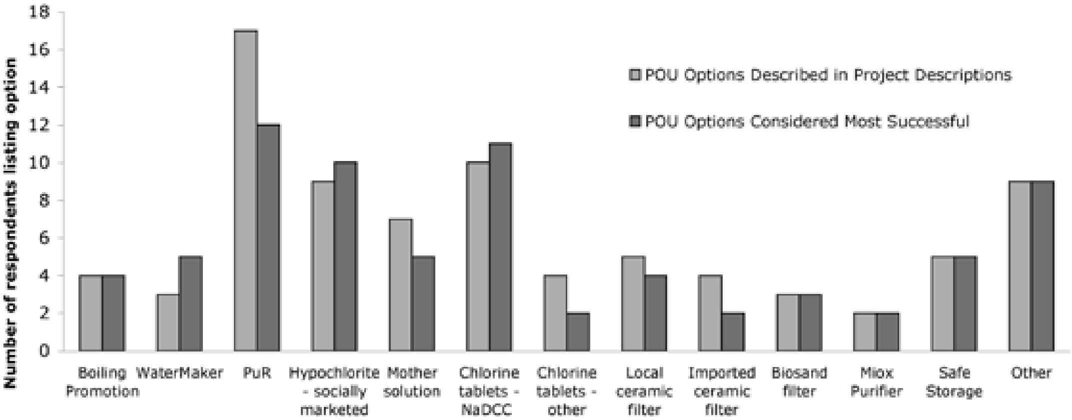

Figure 1. Which PoUWT options were considered most successful?

Table 2. Projects reported in the survey by emergency type and continent

	Africa	*Americas*	*Asia*	*Total*
Natural disaster: cyclone/ waterlogging	1	1	10	12 (16%)
Natural disaster: flood	10	6	11	27 (36%)
Natural disaster: tsunami			9	9 (12%)
Natural disaster: earthquake		3	4	7 (9.3%)
Natural disaster: flood and				
Outbreak: cholera	2			2 (2.7%)
Outbreak: cholera	11			11 (14.7%)
Outbreak: Ebola, hepatitis E, typhoid	3			3 (4%)
Complex emergency	4			4 (5.3%)
Total	31 (41.3%)	10 (13.3%)	34 (45.3%)	75

The 75 remaining projects occurred in 25 countries, encompassing a variety of emergencies (Table 2). Fifty-one (68 per cent) projects began in the acute emergency stage, 6 (8 per cent) in late emergency, and 5 (6.7 per cent) post-emergency. The average number of weeks to respond to the emergency with PoUWT was 3.7 (range 0–36). The majority (68 per cent) of PoUWT projects were implemented in rural areas. The remaining were in urban areas (21.3 per cent) or mixed urban/rural (10.7 per cent) locations. Recipients lived primarily in communities (58.7 per cent), followed by internally displaced (28.0 per cent), refugee (6.7 per cent), and mixed (6.7 per cent) settings.

Projects began between 1999 and 2008. The 66 projects started between 1999–2007 fit an exponential growth curve (R^2=0.92).

Technical assistance was obtained locally within the respondents' organizations in 39 (50.6 per cent) projects, locally outside the respondents' organization in 22 (28.6 per cent) projects, within the respondents' organization internationally in 23 (29.9 per cent) projects, and outside their organization internationally in 4 (5.2 per cent) projects. One project implementing mother solution indicated technical assistance was needed, but not available. Respondents reported that project assessments were completed for 68 (90.7 per cent) projects.

Survey respondents reported an average of 2.16 water sources (range 1–3) used per project. Seventy (43.3 per cent) of the 162 total sources listed were 'improved' (such as infrastructure, protected well, protected spring). The remaining 92 sources (56.7 per cent) were unimproved (surface water, open well, unprotected spring). Data from the 56 projects using only one PoUWT option were analysed separately. Fifty-four single-option projects were stratified into four PoUWT option categories: filters, flocculant/disinfectant, sodium hypochlorite, and chlorine tablets. One boiling and one alum project were not categorized. Flocculant/disinfectants were targeted more often (68.2 per cent) to unprotected water sources, and chlorine tablets were targeted more often (72.2 per cent) to areas with protected water sources, although this result was not statistically significant. Filters and sodium hypochlorite were targeted slightly less, 45.8 per cent and 44.4 per cent of projects, respectively, to protected sources.

Data collected from the following questions was considered too unreliable to report: units of PoUWT product distributed, target population size, cost of product to the organization, time to receive the products, and whether products were available locally or imported.

Availability of product was the largest reason for use mentioned

The particular PoUWT option(s) used were selected for 184 reasons (Figure 2). An average of 2.45 reasons were listed per project (range 0–5). Availability of product was the most frequent reason for use, mentioned in 64 per cent of projects. Local water quality or user acceptability accounted for few reasons for use.

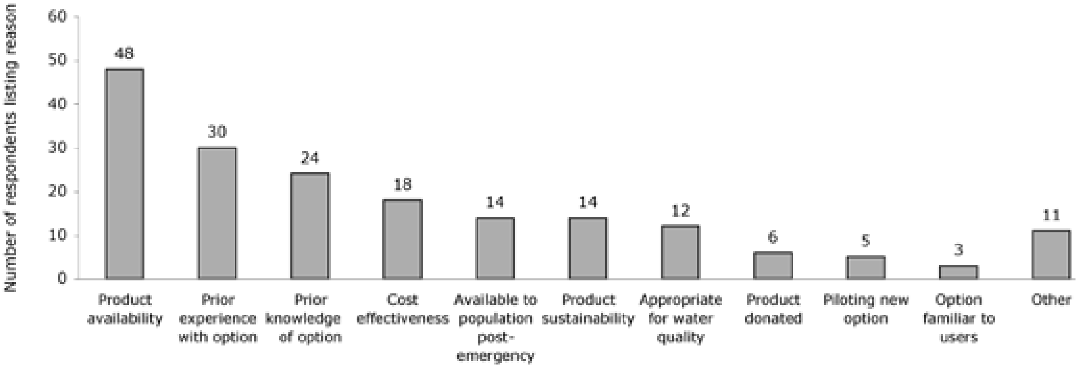

Figure 2. Reasons given for selecting PoUWT option

Product sustainability is a reason for selection of locally manufactured or longer-lasting products

When stratified by single-option projects, flocculant/disinfectants were selected more often because of product availability, appropriateness for water quality, or donation. Product sustainability was mentioned as a reason for selection of locally manufactured or longer-lasting products, such as sodium hypochlorite and filters. Chlorine tablets were the only option where 'familiarity to users' was considered. These data were not statistically significant owing to small sample size.

'Product' responses were considered the easiest factors in implementation, while 'user' responses and product distribution were considered the most difficult factors (Figure 3). Users were trained using group demonstrations in 62 (80.5 per cent), written materials in 28 (36.4 per

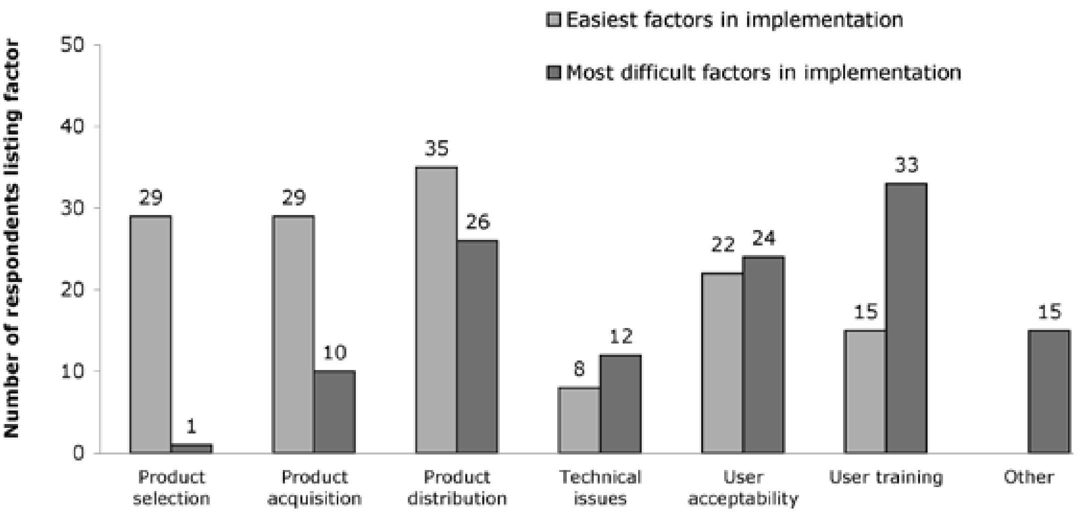

Figure 3. The most easiest and difficult factors in implementing PoUWT

cent), and one-on-one training in 20 (26.0 per cent) projects. Focus group demonstrations were completed in nine (11.7 per cent), and no training was conducted in six (7.8 per cent) projects.

User concerns relate to aesthetics, preference for piped water, and managing the use of the product

When stratified by single-option projects, user acceptability was noted as an easy factor in implementation in filter projects, chorine tablets were noted most often as easy to distribute, and difficulties with user acceptability were noted the most for chlorine tablets. Product distribution and user training was noted as a difficult issue for filter projects. These data were not statistically significant owing to small sample size.

The main user concerns expressed related to aesthetics, preference for piped water, and managing the use of the product (Table 3). Other concerns included (each mentioned once): lower efficacy in this product than another used before, never seen product before, boiling familiar and practical while this product is new, not enough water treated, price too high to purchase post-emergency, not enough water available, product did not have a faucet, product might be harmful, product was not sufficiently available, and there was religious objection to the product. The majority of positive user responses expressed about PoUWT products, as reported by respondents, were health-related.

Discussion

Overall, product options dominate how PoUWT research in emergencies has been conducted. One-third of the research identified in the literature review was sponsored or conducted by one private

Table 3. Survey data on concerns and positive aspects of PoUWT products expressed by users, reported by implementers

Concerns about products expressed by users (reported by respondent)		*Positive aspects of products expressed by users (reported by respondent)*	
Concern	*Number and % of 75 projects*	*Positive aspect*	*Number and % of 75 projects*
Aesthetics (taste, colour, odour)	34 (44.2%)	Providing safe water	42 (54.5%)
Preference for piped water	9 (11.7%)	Health benefit	38 (49.4%)
Too much time to use	8 (10.4%)	Ease of use	29 (37.7%)
Cleaning/maintaining product	7 (9.1%)	Aesthetic benefit	10 (13.0%)
Difficult to use	4 (5.2%)	Cost	1 (1.3%)
None	5 (6.5%)		
Other	11 (14.3%)		

company, Procter & Gamble, on the PuR product. Only 4 of the 28 (14.3 per cent) reports identified for the literature review reported on multiple-PoUWT option reports. Only 19 (25.3 per cent) of 75 projects described in the survey used multiple PoUWT options, and the majority of the reasons respondents picked PoUWT options were product related; 64 per cent of projects reported 'product availability' as the reason for use. This focus on showing how a specific PoUWT option is effective in specific emergencies obscures the more important research questions of which PoUWT options are most effective at microbiological and disease reduction, most appropriate, cost effective, usable by the target population, and sustainable across different stages and types of emergency. In the following sections, a cross-option comparison of data addresses these questions. Further research on PoUWT should focus less on individual products and more on holistic programming.

Literature review

There is some evidence PoUWT is effective in non-acute emergency settings

There is some evidence that PoUWT is effective in non-acute emergency settings. PuR use has been shown to reduce diarrhoeal disease in one refugee camp and improve microbiological quality of household water in cyclones. Sodium hypochlorite use improved microbiological quality of water after the tsunami and during a complex emergency. Ceramic filters have been shown to improve microbiological quality of water during and after flooding. In addition, survey respondents' consider the majority of PoUWT options they have used to be successful, suggesting high acceptability of PoUWT among those promoting and distributing them. Non-significant diarrhoeal disease results in sodium hypochlorite response to cholera and a refugee camp safe storage project could be attributed to small sample size, although that is unknown.

Health impact and microbiological reduction are gold standards for measuring PoUWT impact; however, these metrics can be difficult to assess in emergencies. Some projects described herein were able to gather valuable impact metrics, such as chlorine residual in household water and quantitative information on use and acceptance. Other metrics collected, such as non-controlled self-reported diarrhoeal disease data or knowledge of method to reduce diarrhoea, might be less valuable. Appropriate metrics to assess PoUWT impact, considering what is realistic to collect and analyse in emergencies, rather than the perceived need to obtain health outcomes, should be utilized.

Training is key for PoUWT uptake

Training is key for PoUWT uptake in, and continued use after, emergencies. High usage of PuR in emergencies was associated with a training session and additional follow-up education. Sodium hypochlorite use in emergencies was seen in 3–20 per cent of household waters, although higher long-term uptake levels (76.7 per cent in Haiti) were documented when families had follow-up training. A correct usage of 26.3 per cent in ceramic filter users was documented with only one initial training, indicating less follow-up may be needed for durable PoUWT options. Lack of microbiological improvement in boiled water in Indonesia indicates that not all users are boiling correctly, and additional training is needed.

Product costs – not including transportation, distribution, or marketing – of PuR (treats 10 litres), Aquatabs (20 litres), and sodium hypochlorite bottles (1,000 litres) are \$0.035, \$0.015, and \$0.33, respectively. Willingness to pay estimates (for PuR, Aquatabs, ceramic filter replacement parts) were less than product cost except for sodium hypochlorite bottles. Although cost may not factor significantly in emergency response programmes, cost-recovery is critical if continued access to PoUWT in the post-emergency stage is desired.

Each PoUWT option has benefits and drawbacks, and situations where they are most appropriately implemented

Each PoUWT option has benefits and drawbacks, and thus, situations where they are most appropriately implemented. In emergencies, ceramic filters appear to be a more appropriate intervention after the acute emergency has passed, when householders are moving from transitional to permanent situations. Locally made or locally available products with low cost, such as the SWS or chlorine tablets, may be more appropriate for a relief-to-development model where continued access to the products is desired. PuR may be most appropriate in populations using highly turbid water, where community follow-up training can be conducted during the emergency. Boiling may be particularly appropriate among populations familiar with it already, or entrapped populations when they have the materials to practise the method. Safe storage is an important complement to any PoUWT method, especially those that do not provide for residual protection against re-contamination. Using new products in an emergency is not recommended unless user acceptability is assessed before distribution.

Safe storage is an important complement to any PoUWT method

Chlorine dosage

The commercially available chlorine-based PoUWT options – PuR, chlorine tablets, and sodium hypochlorite – all use a fixed chlorine dosage. PuR uses 2.0 mg/L, which adequately maintained chlorine residual in 30 representative water sources of turbidity 0.3–1,724 NTU in western Kenya (Crump et al., 2004). The dosage of chlorine tablets is, generally, 2.0 mg/L for clear water (1 tab) and 4.0 mg/L for turbid water (2 tabs). The dosage for SWS products is 1.875 mg/L for clear water (1 cap) and 3.75 mg/L for turbid water (2 caps), which maintained adequate chlorine residual levels (>0.2 mg/L and <2.0 mg/L for 24 hours after treatment) in 86.6 per cent of 82 clear and

91.7 per cent of 12 turbid water samples tested from representative sources in 13 developing countries (Lantagne, 2008). Treating water >100 NTU directly with sodium hypochlorite was not recommended. Although these fixed dosages lead to chlorine residuals that exceed the recommended WHO chlorine residual for infrastructure treated water at the point of delivery (0.2–0.5 mg/L) (WHO, 2004), these dosage regimes: 1) are below the maximum guideline value of 5.0 mg/L; 2) maintain chlorine residual during 24 hours of storage in the home; and 3) have been specifically approved as 'consistent with the Third Edition of the [WHO] Guidelines [for drinking-water quality]' for household water treatment purposes, where storage of water at the household level causes degradation of chlorine residual over time (Jamie Bartram, World Health Organization, Geneva, personal communication with Eric Mintz, CDC, Atlanta, 2005).

In contrast, emergency organizations generally test each source empirically using a stock solution to determine what dosage leads to chlorine residual of 0.4–0.5 mg/L 30 minutes after treatment (WHO, 2005), or use special chlorine tablets dosing at 5 mg/L (Paul Edmondson, Medentech, Ltd, Ireland, personal communication with D. Lantagne, 2008). Although 5 mg/L does not exceed the WHO guideline value for chlorine residual in drinking water, it does exceed the taste acceptability threshold (WHO, 2004, Lantagne, 2008).

The lack of user acceptability of high chlorine dosages significantly affects chlorination projects

The lack of user acceptability of high chlorine dosages significantly affects chlorination projects in emergencies, and appropriate dosage regimes should be developed. Dosing at 5 mg/L will likely exceed the taste acceptability threshold, and 0.5 mg/L dosage will likely not maintain sufficient residual during household storage of water.

Survey

The survey was widely distributed to individuals involved with PoUWT in development and emergency contexts, and survey respondents represented a diverse group of implementers in the emergency, development, research, and manufacturing sectors, using a large variety of PoUWT options. Implementers consider the majority of the options they have used in emergencies to be 'most successful' according to their own personal definition of success.

The 75 projects described by the 40 respondents represented a diverse geographic coverage across Africa, Asia, and the Americas. Sixty-four (85.3 per cent) projects were implemented in emergencies identified as having high diarrhoeal disease risk from the literature review (such as flooding events and outbreaks). The majority of the projects (68 per cent) began in the acute emergency stage, when the risk of outbreak is highest. Projects generally targeted persons at higher risk of disease and with less access to improved water supplies, such as those living in rural areas, communities, and the internally displaced. Overall, the projects targeted areas with unimproved water supplies (56.7 per cent of supplies), and the specific PoUWT option used in single-option projects was appropriate for the local water sources.

Technical assistance on PoUWT implementation in emergency response was primarily found locally or from within the respondents' organizations. This result highlights that technical assistance should be available locally and specifically targeted for each implementing organization. Although 89.3 per cent of respondents noted that they had assessed their project in some manner, few of these assessments were independent or made available for our review. Thus, the implementers' perception of success cannot be matched with quantitative data showing project feasibility, and knowledge gained from these evaluations cannot be collated and shared as lessons learned.

There is evidence that PoUWT projects in emergencies are growing at an exponential rate, but this may be the result of systematic or reporting bias. Implementers found it difficult to respond to many logistical questions, and thus an amount of water treated in respondents' projects could not be calculated. The scope of PoUWT product distribution in emergencies is not small, as distributors and manufacturers reported supplying enough sodium hypochlorite, chlorine tablets, and PuR sachets to treat 3.3 billion, 1.65 billion, and 171 million litres of water, respectively, in response to emergencies in 2007 alone (Clasen, 2008). It is unknown how much of these products were used at the household level, however.

User acceptance and training were identified as the most difficult factors in implementation

Product reasons (such as availability and knowledge) dominate the PoUWT option selection process as opposed to user reasons, and product factors were considered the easiest factors in implementing PoUWT. Concurrently, user acceptance and user training were identified as the most difficult factors in implementation, and should be considered more fully in project planning. The easiest and most difficult factors in implementation varied between PoUWT options, indicating that implementation strategies should be specialized for each PoUWT option.

Given that interventions in developing countries are often promoted for health reasons, but users change behaviour for other motivations (Scott et al., 2007), the utility of the respondents' reporting health reasons as the main user positive for PoUWT is unclear.

The main limitations of the survey were: 1) non-response and voluntary response bias potentially preventing implementers with failed PoUWT projects from answering the survey; 2) conclusions drawn by implementers are largely subjective, and are, in most cases, not supported by a rigorous and independent assessment; and 3) not enough survey responses were received to conduct stratified statistical analyses.

Based on the investigations reported herein, the authors worked in conjunction with the Sphere project to develop guidelines for organizations interested in implementing PoUWT programmes for inclusion in the new Sphere revision. The revision will state: 1) that PoUWT can be used as an option when centralized treatment is not possible; 2) the options that have been shown to reduce diarrhoea and improve microbiological water quality; 3) that the most appropriate PoUWT option for any given context depends on existing water and sanitation conditions, water quality, cultural acceptability, implementation feasibility, availability of option, and local conditions; 4) that successful emergency household level water treatment implementations should include the selection of culturally acceptable options, provision of adequate material product and appropriate training to the beneficiary recipients; 5) that introducing an untested water treatment option in an emergency should be avoided; 6) that in areas with anticipated risk, pre-placement of PoUWT products should be considered to facilitate a quick response; and 7) the use of locally available products should be prioritized if continued use in the post-emergency phase is desired. A decision tree for PoUWT products was developed and vetted by a committee of experts, and will also be included.

Additional evidence on the following topics is needed: 1) project monitoring and evaluation; 2) efficacy of unproven 'standard interventions'; 3) lessons learned from projects with multiple PoUWT interventions; 4) PoUWT effectiveness in acute emergencies; 5) relative appropriateness of different PoUWT options in emergencies and with different types of training; and 6) PoUWT effectiveness compared with other water and sanitation interventions. Research is also needed to investigate survey respondents' perceptions that: 1) pre-emergency knowledge of a PoUWT option (either via a long-term development project or repeated exposure to the product during emergencies) increases user acceptability and adoption, and decreases the training requirement; and 2) PoUWT use in emergencies encourages long-term water treatment in the household. Lastly, the focus herein has been exclusively on PoUWT in emergencies, and the concurrent potential for water quality improvements and diarrhoeal disease reduction. Further research is indicated to develop guidelines for implementing organizations on how to: 1) include PoUWT as part of the overall strategy in emergency response; and 2) decide whether to use PoUWT at a particular time within a particular emergency.

Conclusions

There is comparatively little rigorous evidence of PoUWT in emergency settings

PoUWT can be an effective water intervention in some non-acute emergencies

In development settings, PoUWT options have been shown to improve the microbiological quality of household water and reduce diarrhoeal disease in users. There is comparatively little rigorous evidence of PoUWT in emergency settings. However, from the rigorous evidence and user surveys, it is known that: 1) PoUWT can be an effective water intervention in some (non-acute) emergencies; 2) current PoUWT projects correctly target emergencies with high diarrhoeal disease risk; 3) considering user preference in PoUWT option selection facilitates implementation; 4) training is crucial to uptake of PoUWT in emergencies; 5) adequate product stocks are necessary for emergency response; 6) difficulties in obtaining local registration hinder projects; 7) users should have all the materials necessary to use the PoUWT options; and 8) chlorine dosage should be considered in light of user acceptability concerns.

In addition, it is known that: 1) there is less documented success of PoUWT in acute emergencies; 2) introducing an untested PoUWT product in an emergency may not be effective; 3) some PoUWT options may be more appropriate in particular emergencies than others; 4) PoUWT should always be one strategy of many to ensure safe water access in emergencies; and 5) the relevance of sustainable, long-term access to the products should be considered in project planning.

References

Aquaya (2005) *Standard Operating Procedure for the Deployment of Procter & Gamble's PUR Purifier of Water in Emergency Response Settings*, Aquaya Institute, San Francisco, CA.

Arnold, B.F. and Colford, J.M. Jr (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', *American Journal of Tropical Medicine and Hygiene* 76: 354–64.

Boschi-Pinto, C., Velebit, L. and Shibuya, K. (2008) 'Estimating child mortality due to diarrhoea in developing countries', *Bulletin of the World Health Organization* 86: 710–17.

Brin, G. (2003) *Evaluation of the Safe Water System in Jolivert Haiti by Bacteriological Testing and Public Health Survey,* Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA.

Caens, C. (2005) *An Evaluation of the User Acceptability of Oxfam's Household Ceramic Filter*, Cranfield University, Silsoe, UK.

CARE (Undated) *Global Development Alliance, Safe Drinking Water Alliance, Report of Findings: Draft Outline,* CARE, Atlanta, GA.

CDC (2008) *Safe Water for the Community: A Guide for Establishing a Community-based Safe Water System Program*, Centers for Disease Control and Prevention, Atlanta, GA.

Clasen, T. (2008) *Scaling Up Household Water Treatment: Looking Back, Seeing Forward*, Public Health and the Environment, World Health Organization, Geneva.

Clasen, T. and Boisson, S. (2006) 'Household-based ceramic water filters for the treatment of drinking water in disaster response: An assessment of a pilot programme in the Dominican Republic', *Water Practice & Technology* 1: 2 doi:10.2166/WPT.2006031.

Clasen, T. and Smith, L. (2005) *The Drinking Water Response to the Indian Ocean Tsunami, including the Role of Household Water Treatment,* World Health Organization, Geneva.

Clasen, T., Schmidt, W.P., Rabie, T., Roberts, I. and Cairncross, S. (2007) 'Interventions to improve water quality for preventing diarrhoea: Systematic review and meta-analysis', *BMJ* 334: 782.

Colindres, R.E., Jain, S., Bowen, A., Mintz, E. and Domond, P. (2007) 'After the flood: An evaluation of in-home drinking water treatment with combined flocculent-disinfectant following Tropical Storm Jeanne – Gonaives, Haiti, 2004', *Journal of Water and Health* 5: 367–74.

Conroy, R.M., Meegan, M.E., Joyce, T., McGuigan, K. and Barnes, J. (2001) 'Solar disinfection of drinking water protects against cholera in children under 6 years of age', *Archives of Disease in Childhood* 85: 293–95.

Crump, J.A., Okoth, G.O., Slutsker, L., Ogaja, D.O., Keswick, B.H. and Luby, S.P. (2004) 'Effect of point-of-use disinfection, flocculation and combined flocculation-disinfection on drinking water quality in western Kenya', *Journal of Applied Microbiology* 97: 225–31.

De Ville De Goyet, C. (2000) 'Stop propagating disaster myths', *Lancet* 356: 762–64.

Doocy, S. and Burnham, G. (2006) 'Point-of-use water treatment and diarrhoea reduction in the emergency context: An effectiveness trial in Liberia', *Tropical Medicine & International Health* 11: 1542–52.

Dunston, C., McAfee, D., Kaiser, R., Rakotoarison, D., Rambeloson, L., Hoang, A.T. and Quick, R.E. (2001) 'Collaboration, cholera, and cyclones: A project to improve point-of-use water quality in Madagascar', *American Journal of Public Health* 91: 1574–76.

Esrey, S.A., Feachem, R.G. and Hughes, J.M. (1985) 'Interventions for the control of diarrhoeal diseases among young children: improving water supplies and excreta disposal facilities', *Bulletin of the World Health Organization* 63: 757–72.

Esrey, S.A., Potash, J.B., Roberts, L. and Shiff, C. (1991) 'Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma', *Bulletin of the World Health Organization* 69: 609–21.

Fewtrell, L. and Colford, J.M. Jr (2005) 'Water, sanitation and hygiene in developing countries: Interventions and diarrhoea – a review', *Water Science and Technology* 52: 133–42.

Fewtrell, L., Kaufmann, R.B., Kay, D., Enanoria, W., Haller, L. and Colford, J.M. Jr (2005) 'Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: A systematic review and meta-analysis', *Lancet Infectious Diseases* 5: 42–52.

Gaffga, N.H., Tauxe, R.V. and Mintz, E.D. (2007) 'Cholera: A new homeland in Africa?' *American Journal of Tropical Medicine and Hygiene* 77: 705–13.

Gallo, W. (2008) *The Jolivert Safe Water for Families Project's Response to the Gonaives Floods*, Jolivert Safe Water for Families, Melbourne, FL.

Gupta, S.K. and Quick, R.E. (2006) 'Inadequate drinking water quality from tanker trucks following a tsunami disaster, Aceh, Indonesia, June 2005', *Disaster Prevention and Management* 15: 213–15.

Gupta, S.K., Suantio, A., Gray, A., Widyastuti, E., Jain, N., Rolos, R., Hoekstra, R.M. and Quick, R.E. (2007) 'Factors associated with *E. coli* contamination of household drinking water among tsunami and earthquake survivors, Indonesia', *American Journal of Tropical Medicine and Hygiene* 76: 1158–62.

Handzel, T. and Bamrah, S. (2006) *Trip Report: Evaluation of Pilot Intervention to Improve Household Drinking Water, Dong Thap Province, Vietnam*, Centers for Disease Control and Prevention, Altanta, GA.

Hoque, B.A. and Khanam, S. (Undated) *Efficiency and Effectiveness of Point-of Use Technologies in Emergency Drinking Water: An Evaluation of PUR and Aquatab in Rural Bangladesh*, Environment & Population Research Centre, Dhaka, Bangladesh.

IMC (2008) *The Gateway Initiative: Sensitizing Children to Promote Healthy Behaviors and Families*, International Medical Corps, Santa Monica, CA.

Johnston, R. (2008) *Preliminary Data: Response to Cyclone Sidr*, UNICEF, Dhaka, Bangladesh.

Lantagne, D. (2006) *Potters for Peace: Filter Production Facility Best Practices*, Potters for Peace, Managua, Nicaragua.

Lantagne, D. (2008) 'Sodium hypochlorite dosage for household and emergency water treatment', *Journal of the American Water Works Association* 100: 106–19.

Lantagne, D. (2009) *WASH Evidence Base/Knowledge Base and Data Collection Methodologies (EB/DCM) Workshop Rapporteur Report*, 26–29 January 2009. Geneva, Global WASH Cluster.

Mong, Y., Kaiser, R., Ibrahim, D., Rasoatiana, Razafimbololona, L. and Quick, R.E. (2001) 'Impact of the safe water system on water quality in cyclone-affected communities in Madagascar', *American Journal of Public Health* 91: 1577–79.

Noji, E.K. (ed.) (1997) *Public Health Consequences of Disasters*, Oxford University Press, New York.

Palmer, J. (2005) *Community Acceptability of Household Ceramic Water Filters Distributed during Oxfam's Response to the Tsunami in Sri Lanka*', London School of Hygiene and Tropical Medicine, London.

Ram, P.K., Blanton, E., Klinghoffer, D., Platek, M., Piper, J., Straif-Bourgeois, S., Bonner, M.R. and Mintz, E.D. (2007) 'Household water disinfection in hurricane-affected communities of Louisiana: Implications for disaster preparedness for the general public', *American Journal of Public Health* 97 Suppl 1: S130–35.

Reller, M.E., Mong, Y.J., Hoekstra, R.M. and Quick, R.E. (2001) 'Cholera prevention with traditional and novel water treatment methods: An outbreak investigation in Fort-Dauphin, Madagascar', *American Journal of Public Health* 91: 1608–10.

Ritter, M. (2007) *Determinants of Adoption of Household Water Treatment in Haiti Jolivert Safe Water for Families (JSWF) Program*, Emory University, Atlanta, GA.

Roberts, L., Chartier, Y., Chartier, O., Malenga, G., Toole, M. and Rodka, H. (2001) 'Keeping clean water clean in a Malawi refugee camp: A randomized intervention trial', *Bulletin of the World Health Organization* 79: 280–87.

Schmidt, W.P. and Cairncross, S. (2009) 'Household water treatment in poor populations: Is there enough evidence for scaling up now?' *Environmental Science & Technology* 43: 986–92.

Scott, B., Curtis, V., Rabie, T. and Garbrah-Aidoo, N. (2007) 'Health in our hands, but not in our heads: Understanding hygiene motivation in Ghana', *Health Policy Plan* 22: 225–33.

Sobsey, M., Stauber, C.E., Casanova, L.M., Brown, J. and Elliott, M.A. (2008) 'Point of use household drinking water filtration: A practical, effective solution for providing sustained access to safe drinking water in the developing world', *Environmental Science & Technology* 42: 4261–67.

SP (2006) *PUR-Purifier of Water IDP Camp Distribution Program, Lira District, Northern Uganda, Project End Report*, Samaritan's Purse, Boone, NC.

Sphere (2004) *Humanitarian Charter and Minimum Standards in Disaster Response*, The Sphere Project, Geneva.

Toole, M. and Waldman, R.J. (1990) 'Prevention of excess mortality in refugee and displaced populations in developing countries', *JAMA* 263: 3296–302.

UNICEF (2007) *Demonstration Project: Investing in Safe Water for Children – PuR Pilot Application in Vietnam. Final Report to the United States Fund for UNICEF/ Procter & Gamble*, UNICEF Viet Nam Water, Environment & Sanitation (WES) Programme, Vietnam.

UNICEF/WHO (2008) *Progress on Drinking Water and Sanitation: Special Focus on Sanitation*, UNICEF/WHO, Geneva.

Walden, V.M., Lamond, E.A. and Field, S.A. (2005) 'Container contamination as a possible source of a diarrhoea outbreak in Abou Shouk camp, Darfur province, Sudan', *Disasters* 29: 213–21.

Watson, J., Gayer, M. and M, C. (2007) 'Epidemics after natural disasters', *Emerging Infectious Diseases* 13: 1–5.

WHO (2004) *Guidelines for Drinking-water Quality, 3rd Edition; Volume 1: Recommendations*, WHO, Geneva.

WHO (2005) *Household Water Treatment and Safe Storage Following Emergencies and Disasters*, World Health Organization, Geneva.

WHO (2008) *Guidelines for Drinking-water Quality: Second Addendum to Third Edition*, World Health Organization, Geneva.

Zehri, M. and Ensink, J.H. (2008) *Assessment of Nerox™ Water Treatment Device in Emergency Settings in Pakistan*, Oxfam and LSHTM, London.