Household-Based Ceramic Water Filters for the Treatment of Drinking Water in Disaster Response: An Assessment of a Pilot Programme in the Dominican Republic

T Clasen[1] & S Boisson[2]

[1] London School of Hygiene & Tropical Medicine, Keppel St., London, England WC1E 7HT, thomas.clasen@lshtm.ac.uk

[2] International Health Research Associates, Ltd., Milwaukee, WI 53211 USA, sophie.boisson@gmail.com

Abstract As part of its response to flooding in the Dominican Republic in 2003, Oxfam GB distributed ceramic "candle" water filters to householders in 7 affected communities. In a randomized, controlled trial conducted among 80 householders in one community during the six-month design life of the ceramic filter elements, faecal water contamination was consistently lower among intervention households than control households (geometric mean themotolerant coliform (TTC) of 2.9/100 ml vs 32.9/100 ml, $p<0.0001$). Overall, 70.6% of samples from the intervention households met WHO guidelines for zero TTC/100 ml compared to 31.8% for control households ($p < 0.001$). A cross-sectional study 16 months following filter distribution revealed that 88.7% of the filters were still in the recipient households; 48.7% were still operating properly, the others failing mainly due to breakage, clogging or expiration of the useful life of the candle elements. While source waters were still highly contaminated, 54% of samples from working filters were free of TTC. These results suggest that ceramic water filters can be an effective intervention for providing populations affected by disasters with safe drinking water during resettlement. They may also be a potentially sustainable long-term solution, provided householders have access to affordable replacement filter elements.

Keywords drinking water, emergency, filter, floods, household, water treatment

Introduction

Unsafe drinking water, along with inadequate supplies of water for personal hygiene and sanitation, are the main contributors to an estimated 4 billion cases of diarrhoea each year, causing 1.8 million deaths mainly among children under 5 years of age (WHO 2005). A growing body of evidence has shown that treating water at the household level is both more effective and cost-effective in preventing diarrhoeal disease than conventional approaches such as the installation of protected wells and springs (Fewtrell et al., 2005; Hutton and Haller, 2004; Clasen et al., 2006). Even where water is safe at the source, unless protected by residual disinfection or improved storage, it is frequently subject to extensive recontamination during collection, storage and household use (Wright et al., 2003; Trevett et al., 2005). The revised Sphere Standards for humanitarian relief recognize the risk of recontamination (Sphere Project, 2004), and like the WHO, promote household water treatment as an option in emergency response as well as development settings (http://www.who.int/household_water/en/).

Among the options for household water treatment, ceramic filters have been shown to the effective in a variety of development settings (Clasen et al. 2005). Non-governmental organizations (NGOs) have used both commercial and locally-fabricated units to improve the drinking water of communities in at least 17 countries over the past five years. Such filters have been shown to offer certain advantages over chemical and other approaches to point-of-use water treatment, including their high microbial efficacy, low cost, long life, effectiveness in a wide variety of water conditions (temperature, pH, turbidity), and high levels of acceptability by the target population.

The success of ceramic water filters in development settings has led some NGOs to explore their use in emergency response (Smith, 2004; Caens, 2005). While the risk of waterborne disease following natural disasters is often exaggerated (Floret et al., 2006), governments often respond by encouraging affected populations to boil or chlorinate drinking water until supplies of treated water are restored. Experience in Indonesia following the Indian Ocean tsunami demonstrated these approaches can be ineffective in providing displaced people with safe drinking water (Clasen et al., 2006a). Bulk water supplies can be equally contaminated (Gupta & Quick, 2006). Responders are therefore seeking other alternatives, and are especially eager to introduce solutions that could continue to serve the affected populations on a long-term basis.

In late 2003, heavy rains and poor water management caused severe flooding in the Montecristi District of the Dominican Republic, located in the country's northwest corner along the border with Haiti. Dozens of communities and tens of thousands of people were affected. When victims left temporary shelters after about two weeks to return to their homes, emergency responders faced the need to provide safe drinking water to thousands of householders whose normal surface and other sources were destroyed or contaminated. Householders were mainly relying on rainwater collection and water supplied commercially, either in 20L bottles of "purified" drinking water (US$0.46) or from tanker trucks that filled household barrels with water that was purportedly chlorinated (US$0.86 for 55 gallons). After testing showed all these sources to be faecally contaminated, Oxfam GB implemented various interventions, including a pilot programme in February 2004 to provide 431 families with a water filter designed for household use. At their request, we undertook an assessment of the programme to evaluate the microbiological performance, use and acceptability of the filters.

Methods

Each filter was fabricated from two locally-procured 20L buckets with lids, three imported Brazilian (Ceramica Stefani/First Water) "candle" filter elements, and a plastic tap. The design has been illustrated and described elsewhere (Clasen et al., 2005). Threaded nipples on the bottom plates of the hollow, can-shaped candles are inserted through holes made in the bottom of the top bucket and lid of the bottom bucket, sealed with the accompanying gaskets and wing nut, and a tap is inserted into the hole in the bottom bucket. When water is poured into the top bucket, gravity drives it through the porous ceramic media at a rate of approximately 1L per hour per candle into the bottom bucket where it can be accessed only by means of the tap. The Stefani candles have been independently tested to reduce faecal bacteria by 4 logs (99.99%) and, according to the manufacturer, have a design life of approximately 6 months. With a nominal pore size of 1.0 micrometres, the candles should also be capable of mechanically removing protozoan cysts and oocysts (>3 micrometres), though no test results were provided. The candles are not capable of removing viruses (20-100 nanometres) except incidentally when they adhere to bacteria and other larger particles. The hollow core is filled with granular activated carbon (GAC) to reduce chemical contaminants and improve water taste, and both the outside and inside surfaces are treated with colloidal silver for bacteriostasis. The cost of the entire filter system was approximately US$15.00, though they were distributed free of charge. After a visit to prospective recipients by community mobilizers to discuss water, sanitation and hygiene issues, the filter components were trucked to each community where they were assembled and taken home by participating householders.

We assessed the bacteriological performance of the filters by conducting a randomized, controlled trial to compare the level of thermotolerant coliforms (TTC), a indicator of faecal contamination (WHO, 2004), in the stored drinking water of filter users and a control group that continued to follow their customary water management practices. Following a baseline survey to collect information on demographics, household economics and water, sanitation and hygiene practices, 80 households in the community of Nueva Judea who consented in writing to participate in the study after a meeting providing full details were randomly allocated, half to the intervention group who received the filters and half to the control group. Thereafter, an investigator from Mujeres en Desarrollo (MUDE), Oxfam's local partner, made an unannounced visit to each of the participating households once each month for 6 months to collect water samples for analysis. Samples from intervention households were collected directly from the filter tap; samples from control households were collected directly from the vessel identified by the householders present to be used for drinking. Following the 6-month trial, control households were given their own filter.

All water samples were kept on ice and analyzed within 4 hours of collection by laboratory staff of the Dominican Public Health and Social Care Office (SEPAS) . Sample water was passed through a 0.45µ membrane filter (Millipore Corporation, Bedford, Massachusetts, USA) and incubated on membrane lauryl sulphate media (Oxoid Limited, Basingstoke, Hampshire, England) at 44°C ± 0.5°C for 18 hours in an Oxfam Delagua portable incubator (Robens Institute, University of Surrey, Gilford, Surrey, UK). Yellow colonies appearing on the membrane grid were counted and recorded as individual colony forming units (CFU) of TTC. Geometric mean TTC counts were calculated (substituting 1 for 0, as necessary) and the differences in means were assessed for statistical significance using the t-test, after controlling for repeated samples from the same household.

Sixteen months following the distribution of the filters, we returned to Montecristi to conduct a cross-sectional follow-up study in all 7 communities in which the filters were distributed. Though the ceramic candle elements had a design life of only 6 months, replacement elements were available in certain areas (for approximately US$4.50 per candle), and Oxfam was eager to learn to what extent householders would replace candles and continue to use the filter system. In addition to sampling and analysing water from the sources of supply then being used by community members (surface water, locally-produced bottled water and tanker trucks that filled household barrels) and from operating filters, we assessed the use and acceptability of the filters by conducting surveys and structured interviews among householders who had received the filters.

Results and discussion

Baseline data did not reveal any statistically significant differences between intervention and control groups in terms of household size or other demographics, economic indicators, water handling practices, sanitation facilities or hygiene practices, except that members of the intervention group were more likely to use tanker trucks as a source of water supply. Table 1 shows, for each month during the trial, the number of samples collected and the geometric mean TTC count (and 95% confidence interval) for the intervention and control groups, as well as the p-value for the difference between the means. Overall, the geometric mean TTC count was 2.95 (95%CI: 2.14, 3.76) for the intervention group versus 32.88 (95%CI: 21.85, 43.91) for the control group, a difference that was highly significant ($p<0.0001$).

	Control		**Intervention**		
	N	**Geo mean (95%CI)**	**N**	**Geo mean (95%CI)**	**p-value (t-test)**
1	29	14.3 (5.4, 37.5)	33	1.82 (1.0, 3.1)	0.0002
2	34	39.6 (16.2, 96.8)	37	1.90 (1.2, 3.0)	<0.0001
3	31	6.7 (2.9, 15.4)	32	2.42 (1.3, 4.6)	0.0527
4	33	32.3 (13.7, 76.4)	29	2.42 (1.3, 4.6)	<0.0001
5	34	26.9 (11.3, 64.3)	29	3.62 (1.7, 7.7)	0.0009
6	34	14.3 (6.0, 34.0)	27	3.41 (1.6, 7.3)	0.0164
Overall	**195**	**32.9 (21.9, 43.9)**	**187**	**2.9 (2.1, 3.8)**	**<0.0001**

Table 1. Themololerant coliform (TTC) count in water samples from control and intervention households during the 6-month trial in Nueva Judea following distribution of the filters.

The bacteriological performance of the filters can also be assessed based on their capacity to reduce the portion of water samples presenting higher levels of faecal contamination. Table 2 sets forth the percentage of samples examined that fall into the various WHO risk categories for faecal contamination: 0 TTC/100 ml (in compliance), 1--10 TTC/100 ml (low risk), 11--100 TTC/100 ml (intermediate risk), and 101--1000 TTC/100 ml (high risk) (WHO 1997). Overall, 70.6% of samples from the intervention households met WHO guidelines for zero TTC/100 ml compared to 31.8% for control households ($p < 0.001$). Conversely, 34.5% of samples from control households had 101--1000 TTC/100 ml compared to 5.9% of samples from intervention households ($p < 0.001$). While 82.9% of intervention group samples were in compliance or presented low risk, 60.0% of samples from control group households presented intermediate or high risk.

		Percentage of samples by WHO risk category (TTC/100ml)				
Month	**Group**	**0**	**1-10**	**11-100**	**101/1000**	**p-value (Chi^2)**
1	Control	37.9%	10.3%	20.7%	31.0%	<0.001
	Intervention	78.8%	9.1%	6.1%	6.1%	
2	Control	26.5%	2.9%	20.6%	50.0%	0.006
	Intervention	75.7%	10.8%	10.8%	2.7%	
3	Control	51.6%	9.7%	22.6%	16.1%	0.215
	Intervention	75.0%	9.4%	9.4%	6.2%	
4	Control	21.2%	12.1%	27.3%	39.4%	<0.001
	Intervention	69.0%	13.8%	13.8%	3.4%	
5	Control	23.5%	17.6%	20.6%	38.2%	0.016

		Percentage of samples by WHO risk category (TTC/100ml)				
	Intervention	55.2%	24.1%	10.3%	10.3%	
6	Control	32.3%	14.7%	23.5%	29.4%	0.040
	Intervention	66.7%	7.4%	18.5%	7.4%	
Overall	**Control**	**31.8%**	**11.3%**	**22.6%**	**34.4%**	**<0.001**
	Intervention	**70.6%**	**12.3%**	**11.2%**	**5.9%**	

Table 2. Percentage of samples by WHO risk category from control and intervention households during the 6-month trial in Nueva Judea following distribution of the filters.

Table 3 summarizes data collected on use of the filters during a follow-up study approximately 16 months following their distribution. Visits to about a quarter (115/431) of the households that received the filters in all 7 communities in which they were deployed revealed that 88.7% of the households still had the filters in their possession, and 48.7% were still working (i.e., no broken or missing parts, correctly assembled, and still in use by the householder). In total, 23 (41%) households had changed the first set of candles within 6 months of distribution, 11 (21%) between 6 months and a year, and 20 (38%) were still using the same filter elements after 16 months. Of the 13 families that no longer had the filters, most had given them to relatives and 2 had sold them. In total, 34 (33%) of the filters were not being used to filter water, mainly because the householders no longer had working candle filters due to breakage (22), clogging (6) or leaking of GAC into the product water (4). Householders reported that the ceramic candle breakage occurred when systems accidentally fell from a table or other surface or during cleaning or replacement. For those filters no longer in use, the average period of operation reported by householders was 9 months. Most filters that were no longer operational were nevertheless being used, mainly for storing drinking water in the home or for rainwater collection.

Community (and No. filters initially distributed)	No. houses visited	No. (%) households with filter	No. (%) households using filter	No. (%) households with working filters
B.Jaramillo (47)	11	6 (54.5)	4 (36.4)	3 (27.3)
B.Juliana (58)	20	16 (80.0)	13 (65.0)	13 (65.0)
B.Higuero (66)	11	11 (100.0)	6 (54.5)	6 (54.5)
B. La Cruz (108)	30	30 (100.0)	24 (80.0)	18 (60.0)
Los Maury (15)	5	5 (100.0)	2 (40.0)	2 (40.0)
La Recta Sanita & Saman (57)	21	18 (85.7)	4 (19.0)	2 (9.5)
Nueva Judea (80)	17	16 (94.1)	15 (88.2)	12 (70.6)
TOTAL	**115**	**102 (88.7)**	**68 (59.1)**	**56 (48.7)**

Table 3 Data on use of filters from 16-month follow-up study among all 7 communities in which they were distributed

Filters were mostly located on stable surfaces (84%), in hygienic areas such as kitchens (78%), and 65% appeared clean. Households filtered primarily rain water (76%), but also bottled (43%) and tankered water(42%), and piped water (31%) in Higuero and La Cruz. The majority were filling the system once a day (51%) or once every other day (18%) on average. Filtered water was commonly used for drinking purposes only (73%), occasionally for both cooking and drinking (20%), and rarely for cooking only (7%). Almost all persons interviewed (92%) found the quantity of water produced sufficient for their family – the average size of households in the survey being 4 persons. 83.6% liked the taste of filtered water, and a few (16.4%) would define it as “regular” in taste. The taste was apparently better when using rain water than tanker-supplied water. Some mentioned the bad chlorine taste of tanker-supplied water was not improved with filtration. Despite finding the quantity of water sufficient and the taste good, 33 households (51%) were also drinking from other water sources without filtering it, mainly from commercially-supplied “purified” bottles (27). Some mentioned drinking it when not at home, or when no tinkered water or rainwater is available for filtering.

During the 16-month follow-up, 14 water samples were collected and analyzed from source water (7 from stored rainwater, 4 from commercially-supplied bottled water, and 2 from tanker trucks). Geometric mean TTC counts per 100 ml were 240.8 (range, 18 to 6000) from the stored rainwater, 20.3 (0 to 300) from the bottled water, and 788.4 (420 and 1480) from the tankered water. During this same period, 41 water samples were collected and analyzed from the 56 working filters (73.3%), it being impossible to collect water from all filters as many were empty at the time of the visit. In all, 56 percent of the samples were free of TTC; 10%, 27% and 7% fell within the WHO categories for low risk (1-10 TTC/100ml), intermediate risk (11-100 TTC/100ml) and high risk (101 to 1000 TTC/100ml), respectively. None were higher than 1000 TTC/100ml.

Conclusions and recommendations

The results suggest that household-based water filters fabricated locally from imported ceramic candle elements are effective in improving the bacteriological quality of drinking water among a population affected by flooding. They also suggest that the filters are acceptable to the population, and at least a portion of the population will continue to use the filters for at least 16 months after they received the same, purchasing their own replacement candles in many cases. The chief reasons for discontinuing use appear related to the hardware—breakage, clogging or simply expiration of the useful life of the ceramic elements—and not to the sale or other disposal of the filters or to non-acceptability by the target population. In general, this evidence suggests that the household-based water filters were largely embraced by the target population and that use continued well beyond the flooding event.

These results are similar to unpublished data from Haiti which showed similar filters to be microbiologically effective and highly acceptable to a flood-affected population (Caens, 2005). They are in contrast, however, with unpublished data from Cambodia in which locally-fabricated pot-style filters and lower-quality commercial filters reduced source water contamination by only 1log (90%) when deployed in a post-flood setting (Smith, 2004). Pot-style filters may be subject to contamination of the bottom vessel during cleaning and maintenance; lower-quality ceramic elements can remove turbidity, thereby improving water aesthetics, but are not suitable for microbial protection. The adoption and use of the filters in this case and in Haiti is also in contrast with their uptake in Sri Lanka immediately following the Indian Ocean tsunami (Clasen et al., 2006a). This may be attributable to the fact that in the Dominican Republic, the filters were deployed well after the emergency phase of the disaster to a population that had already returned to their homes from temporary shelters. It may also be attributable to more effective training of householders in the use and maintenance of the filters. While such training is vital, the evidence from the Dominican Republic is that it does not have to be extensive.

One of the possible advantages of deploying ceramic filters in emergency response is their potential to provide a population with a means of treating their water well after the immediate emergency. Insofar as filters are portable and highly valued (here, even the non-operational filter systems were retained and used), they can be distributed in temporary shelters where training can be provided, and taken back and used at the household level when families re-settle. At the same time, the fact that less than half of the households changed their ceramic filter elements after their six-month useful life and that more than a third were still using the filters after one year demonstrates an important shortcoming in the use of ceramic filters over the long term. Ceramic candles tend to loose their microfiltration capacity when the they loose wall thickness due to successive cleaning of the outer surface to remove particles and biofilm that reduce flow rate. Unpublished data from Haiti showed a clear trend in which fewer filters produced microbe-free water over time (Caens, 2005).

In order to ensure that the systems continue to provide sufficient protection against microbial pathogens, programme implementers must convince householders of the need to replace the filter elements periodically. Equally important, they must establish a means by which householders can obtain access to affordable filter elements. Cost may not be the major obstacle; in the follow-up interviews, most householders reported that they were willing to purchase replacement candles but did not know where they could buy them. This does suggest that the intervention may be sustainable. However, creating an ongoing source of supply of replacement parts may be especially difficult in disaster response, when many responders leave the area soon after the emergency subsides. If the continued supply of replacement candles cannot be assured, one alternative is to use longer-lasting candles at the outset. In Colombia, where access to populations affected by a conflict could not be assumed, Oxfam used Swiss-based Katadyn candles with a 20,000L capacity, thus potentially providing continued service for 3 years or more (Clasen et al., 2005). While these candles cost three or four times more than the Stefani candles used in the present case, they may be more cost-effective over their useful life.

Owing in part to the fact that this assessment was undertaken of a pilot programme, certain shortcomings in its methodology should be noted. First, this study was not blinded, either at the level of the intervention or assessment. Certain studies of household-based water treatment interventions that have employed a placebo-controlled, double blind design found no statistically significant difference between intervention and control groups, though other single-blinded studies have found the intervention to be effective, much like the great majority of studies of household-based water treatment (Clasen et al., 2006). Second, as a result of the remoteness of the study sites and the lack of on-site investigators, there was no rigorous means of assessing compliance with the intervention. Participants acknowledged that they did not always drink filtered water. The effectiveness of household-based water treatment has been shown to be conditioned upon compliance with the intervention (Fewtrell et al., 2005; Clasen et al., 2006). Third, while the intervention was randomly allocated within each study setting following a method that ensured an appropriate generation of the allocation sequence and concealment of such sequence, the selection of the study communities was not random but made by Oxfam in an attempt to obtain a representation of the types of settings in which it operates in the Dominican Republic. Finally, the outcomes of this study—bacteriological performance of the filters and their use and acceptability by the target population—is only indicative of their potential impact on health. In order to measure the actual health benefits of the intervention, the study would need to include a disease outcome such as diarrhoea.

Subject to these qualifications, the results of this study suggest that household-based water filters using higher-quality ceramic candle elements may be an effective intervention for providing a population affected by flooding with safe drinking water when they return to their homes and for some time thereafter. Since deployment requires certain logistical and programmatic support, the deployment should perhaps be deferred until the resettlement phase of the emergency rather than in the initial stabilization and recovery phases. The filters can continue to provide effective water treatment well beyond the emergency, and may even be sustainable through householder contributions, provided the population has ready access to affordable replacement filter elements.

Acknowledgements

The authors acknowledge with gratitude the contributions to this study by Andy Bastable, Tim Forster, Simon Parry and Lisette Verheijen of Oxfam GB; Maria Dolores, Ana Gomez and Manuel Perez of Mujeres en Desarrollo (MUDE); and the laboratory staff of the Dominican Public Health and Social Care Office (SEPAS).

References

Caens C (2005). *An evaluation of the user acceptability of Oxfam's household ceramic filter*. MSc Thesis, Cranfield University, Silsoe, UK.

Clasen TF, Garcia Parra G, Boisson S, Collin S (2005). Household-based ceramic water filters for the prevention of diarrhea: a randomized, controlled trial of a pilot program in Colombia. *Am J Trop. Med. Hyg*. 73(4):790-795

Clasen T, Roberts I, Rabie T, Cairncross S (2006). Interventions to improve water quality for preventing infectious diarrhoea (Cochrane Review). In: The Cochrane Library, Issue 3, 2006. Oxford: Update Software

Clasen T, Smith L, Albert J, Bastable A, Fesselet J-F (2006a). The drinking water response to the Indian Ocean tsunami, including the role of household water treatment. *Disaster Prevention & Management* 15(1):190-201

Fewtrell L, Kaufmann R, Kay D, Enanoria W, Haller L , Colford J, 2005. Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *Lancet Infect Dis* 5: 42--52

Floret N, Viel J-F, Mauny F, Hoen B, Piarroux R. Negligible risk for epidemics after geophysical disasters. *Emerg Infect Dis* 12(4):543-548.

Gupta SK& Quick R (2006). Inadequate drinking water quality from tanker trucks following a tsunami disaster, Aceh, Indonesia, June 2005. Disaster Prevention & Management 15(1):213-15

Hutton G, Haller L (2004). Evaluation of the costs and benefits of water and sanitation improvements at the global level. Geneva: World Health Organization

Smith L (2004). *Ceramic water filer use in Takeo, Cambodia—operational issues and health promotion recommendations*. London School of Hygiene & Tropical Medicine, London, UK

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

Trevett A, Carter R, Tyrrel S (2005). The importance of domestic water quality management in the context of faecaol-oral disease transmission. *J Water & Health* 3:259-270

WHO (1997). *Guidelines for Drinking Water Quality*--Vol. 3. Second Edition. World Health Organization, Geneva, Switzerland

WHO (2004). Guidelines for *Drinking- Water Quality*, Vol. 1. Third Edition. World Health Organization, Geneva, Switzerland

WHO (2005). *World Health Report 2005*. World Health Organization, Geneva, Switzerland

WHO/UNICEF (2005). *Meeting the MDG Drinking Water and Sanitation Target: A Midterm Assessment of Progress*. Geneva: The World Health Organization and the United Nations Children's Fund.

Wright J, Gundry S, Conroy (2003). Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Trop. Med. & Int'l Health* 9:106-17