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Point-of-use water treatment and diarrhoea reduction in the emergency context: an effectiveness trial in Liberia

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Summary Communicable diseases are of particular concern in conflict and disaster-affected populations that reside in camp settings. In the acute emergency phase, diarrhoeal diseases have accounted for more than 40% of deaths among camp residents. Clear limitations exist in current water treatment technologies, and few products are capable of treating turbid water. We describe the findings of a 12-week effectiveness study of point-of-use water treatment with a flocculant–disinfectant among 400 households in camps for displaced populations in Monrovia, Liberia. In intervention households, point-of-use water treatment with the flocculant–disinfectant plus improved storage reduced diarrhoea incidence by 90% and prevalence by 83%, when compared with control households with improved water storage alone. Among the intervention group, residual chlorine levels met or exceeded Sphere standards in 85% (95% CI: 83.1–86.8) of observations with a 95% compliance rate.

keywords point-of-use water treatment, household water treatment, flocculant–disinfectant, Liberia, diarrhoea

Introduction

Communicable diseases are of particular concern in populations affected by conflict, natural disasters, famine and mass migrations. In the context of emergencies and disasters that result in large-scale population displacements and densely populated camps, diarrhoeal diseases are an important cause of morbidity and mortality, particularly because the provision of adequate water and sanitation can be fraught with challenges. Diarrhoea is widely considered to be a leading cause of death in camp situations, and epidemic diarrhoea (particularly cholera) is often common. In the acute emergency phase, diarrhoeal diseases have accounted for more than 40% of deaths among camp residents, with over 80% of these occurring in children under 2 years of age (Paquet & Hanquet 1998). In the aftermath of the Rwanda crisis in 1994, 85% of the 50 000 deaths that were recorded among Rwandan refugees in Goma (Democratic Republic of the Congo) were due to diarrhoeal diseases, most notably a cholera epidemic (Goma Epidemiology Group 1995).

The ability to respond to large-scale emergencies and disasters and rapidly provide safe drinking water is essential in order to reduce disease burden and mortality-associated diarrhoeal disease. Excess morbidity and mortality caused by communicable diseases during complex emergencies is largely preventable and effective interventions are available. Assurance of adequate sanitation and water supply, including both water quantity and quality, and hygiene education are the primary means for diarrhoea reduction (Clasen & Cairncross 2004). Outbreak investigations in the camp context have shown that common sources of infection include polluted water sources, contamination of water during transport and storage, shared water containers and cooking pots, scarcity of soap and contaminated foods (Goma Epidemiology Group 1995; Roberts *et al.* 2001). Point-of-use water treatment and improved water storage have been shown to reduce diarrhoea in populations with poor hygiene and sanitation conditions in multiple countries, and point-of-use water treatment in the emergency context has recently been identified as an area where further research is needed (Roberts *et al.* 2001; Sobsey *et al.* 2003; Connolly *et al.* 2004).

In a cost-effectiveness comparison in Africa, the World Health Organization found that point-of-use water disinfection was the most cost-effective method to reduce disease burden associated with risks of unsafe water supply and sanitation (WHO 2005). Sodium hypochlorite (chlorine bleach) is used widely throughout the developing world and is among the least expensive point-of-use water treatment methods; however, its efficacy is reduced when water has high concentrations of organic matter (chlorine rapidly binds to the organic matter and thus is not available to kill microbes) (Semenza *et al.* 1998; Quick *et al.* 1999; Crump *et al.* 2004). If water is only mildly contaminated with organic matter, higher doses of sodium hypochlorite can render it microbiologically safe; however, high chlorine levels adversely affect taste and may decrease the willingness of people to drink the water (Reller *et al.* 2003). When large doses of sodium hypochlorite are used in very turbid water, higher concentrations of potentially toxic compounds can result (Karol 1995).

Clear limitations exist in current water treatment technologies, and products capable of rendering water with high quantities of organic matter safe for drinking are limited; in addition, there is a persistent unmet need for affordable and effective point-of-use water treatment. Conventionally, water treatment for camp populations in the emergency context is at the camp level and not the household level. Household level treatment is becoming increasingly available to responders (e.g. the tsunami response); however, there is limited experience with household level water treatment, partially because water treatment *en masse* is often more feasible in camp settings. In the emergency context where other common treatment methods such as boiling and treatment with sodium hypochlorite are not ideal (such as when water is turbid or cooking fuel is limited), point-of-use flocculant–disinfectant may be highly effective, and in cases where target populations do not reside in camps and are dispersed, household level interventions are necessary. In response, a new flocculant–disinfectant technology for home water treatment that incorporates techniques used in municipal water purification was developed. A 12-week effectiveness study of the flocculant–disinfectant was conducted in two camps for internally displaced populations in Monrovia, Liberia. Permission to conduct the study was obtained from The Liberian Ministry of Health. The Committee for Human Research at Johns Hopkins Bloomberg School of Public Health reviewed and approved the study protocol.

Materials and methods

Study site

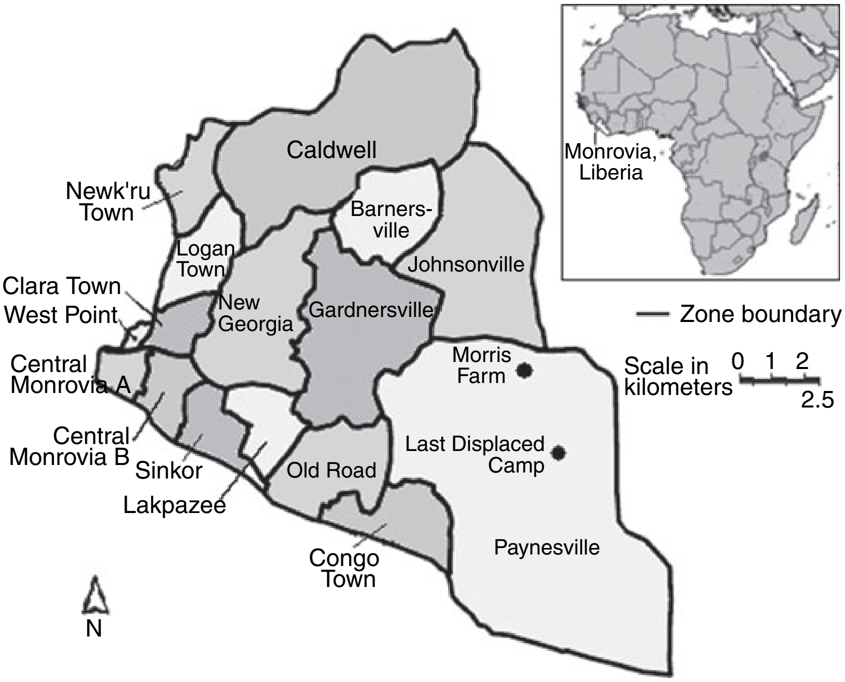
Civil war and political instability have threatened the Liberian population for over a decade. As of 2003, the prolonged conflict had resulted in the internal displacement of an estimated 532 000 people with 200 000 internally displaced people (IDP) residing in camps in the greater Monrovia area; an additional 335 000 have fled the country as refugees (HIC 2003; UNDP 2004). Recent morbidity and mortality reports for Liberian IDP populations placed crude mortality at 2.4/10 000/day, which is above the 1/10 000/day rate used to define the emergency phase in refugee and displaced person situations (Valderrama 2002). A cholera epidemic was reported in the Monrovia area as recently as late 2003; no clinical or epidemiological evidence was available in relation to the presence of cholera at the IDP camps where the study was implemented because of the minimal health infrastructure and laboratory capabilities (Centers for Disease Prevention and Control 2003). A mortality study of Liberian IDPs found that 19% of deaths were attributable to diarrhoea (Valderrama 2002).

The study was conducted over a 12-week period from July to September 2004, which coincided with the later part of the rainy season. Potential study sites were restricted to camps in the greater Monrovia area for security reasons. IDP camps that had particularly poor water quality and no water treatment (either ongoing programmes or known plans for the start-up of water projects) were identified. Two sites, Last Displaced Camp and Morris Farm, were selected based on the initial assessment and logistical considerations (Figure 1). Last Displaced Camp is a relatively large camp, with approximately 3000 households or a total population of around 17 000. Morris Farm is a smaller camp with approximately 1015 households and 5800 individuals. Most shelters in the camps were one-room huts approximately 9–12 m^2 in size with wood, thatch or mud walls; thatch and/or tarp roofs and mud floors. Living conditions in the camps were crowded, with most shelters being no more than 1 m apart; camp residents shared latrines, and adequate disposal of faeces was more apparent problem in Last Displaced Camp than in Morris Farm. Turbidity of water sources was not measured; however, increased turbidity was observed after periods of rainfall and water from open wells tended to be more turbid than water from boreholes.

In general, camp residents had relatively few water storage and transportation vessels and they tended to be relatively small. Primary drinking water sources included boreholes; however, in many instances, pumps were locked for long periods (to allow for recharging) and camp residents used alternative water sources, primarily open wells, as secondary sources. Primary drinking water sources for the study population in Last Displaced Camp included three boreholes and one open well; the primary drinking source in Morris Farm was a single borehole. Lack of household storage containers in conjunction with restricted water availability was reported as key factor that limited water use in both study sites.

Study design and enrolment

After identifying the two trial sites, the sample was stratified by location such that 200 households in each site



Source: Adapted from the Humanitarian Information Centre for Liberia.

Figure 1 Greater Monrovia administrative boundaries and survey sites.

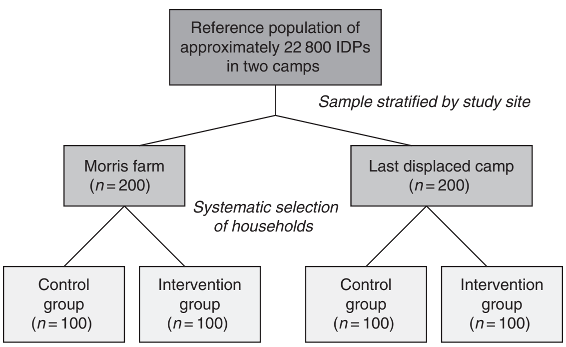


Figure 2 Study sample design.

were selected to participate (Figure 2). The larger camp, Last Displaced Camp, is organised into seven blocks, and three blocks were selected to participate in the trial. Morris Farm is composed of three blocks, all of which participated in the study. Estimates of the total number of households in each block were obtained from camp management and then were revised according to findings of a camp population assessment. In order to minimize contact (and potential transfer of sachets or treated water) between the two participant groups, each block was divided into two or four subsections, and each subsection was randomly designated as an intervention or control area. Sampling intervals varied by block/subsection size and were determined by dividing the total number of shelters in the block by the desired number of participants. Households from within each area were systematically selected (i.e. every *n*th household) to participate in the study based on their assigned plot number.[1] Only households with a child under 5 years of age were eligible to participate in the study, because it was anticipated that diarrhoea prevalence, and thus impact of improved water quality, would be the highest among this group. If the selected household did not meet these criteria, the adjacent plot with a higher number was selected as a replacement. A total of 2215 participants in 400 households were enrolled in the study.

The field team explained the purpose of the study to each prospective household, emphasizing that participation was voluntary and that subjects could withdraw at any time. Written consent was obtained from an adult in each household that was enrolled in the study. A baseline survey was conducted at the time of enrolment to collect basic information including household composition, water access and storage customs, and pre-intervention diarrhoea rates. If no one was present at the initial visit, the interviewer requested that neighbours inform household residents that they would return on the next day. If a second visit to the

[1] Households were systematically selected for participation, and a cluster design was not employed.

household was unsuccessful, the shelter with the next highest plot number was selected as a replacement.

Intervention

The study compared diarrhoea rates among households with flocculant–disinfectant water treatment and improved water storage (intervention group) to households with only improved storage (control group). The improved water storage was selected as a control group intervention for several reasons:

- Limited availability of water storage containers was cited as a problem among IDP camp residents.
- Water is frequently contaminated during the collection, transport and storage process, and improved water storage can help to preserve water quality at the household level (Wright *et al.* 2003).
- Because improved water storage is a component of treatment with PUR® (Procter & Gamble Company, Mason, OH, USA) (water is treated at the bucket level and then must be decanted into a separate storage container), improved water storage among the control group was ideal for comparative purposes, because observed differences in diarrhoea rates can be attributed to treatment with the flocculant–disinfectant.

If the control group did not benefit from improvements in water storage, it would be unclear whether differences in diarrhoea outcomes were attributable to treatment with the flocculant–disinfectant or improved storage.

A sample size of 400 households ($n = 200$ per group) was determined to be adequate to detect a 15% difference in diarrhoea rates between intervention and control groups with 95% precision and 80% power, allowing for a 10% dropout and loss in statistical efficiency because of repeated measures. As a result of these visible effects of treatment with the flocculant–disinfectant on water clarity, the study was not blinded, because differences would have remained apparent to study participants.

Flocculant–disinfectant group. Households in the flocculant–disinfectant group ($n = 200$) received a flocculant–disinfectant product (PUR) for household treatment of water over a 12-week period. Study participants in the intervention group were provided with PUR at no charge; in other contexts, the approximate cost of PUR to consumers is less than 0.01 US$ per litre, and the product is sold at cost ($0.035 per sachet) to relief providers and social marketing groups. The annual cost of PUR is estimated at $11.01 per beneficiary (consumer cost) and $3.83 per beneficiary (relief cost) based on the consumption of 3 l of treated water per day and excluding the cost of household items such as a bucket and mixing spoon.

In the dual flocculation–chlorination process, PUR kills certain bacteria, and has high removal rates of bacteria, viruses and protozoan cysts even in turbid waters (Souter *et al.* 2003). Its ingredients include ferric sulphate and calcium hypochlorite, which are commonly used in conventional water treatment plants, however, they are specially formulated for single-use sachets that treat small volumes of water quickly. The water treatment process was carried out at the household level using a bucket (10 l of water) and combines precipitation, coagulation and flocculation with disinfection with time-release chlorine. The removal of organic matter, bacteria, parasites, viruses and heavy metal is facilitated by the treatment process and mean residual chlorine levels in excess of the minimum Sphere standard of 0.5 mg/l for the disaster context have been consistently reported in treated water (Rangel *et al.* 2003; Souter *et al.* 2003; Sphere 2004).[2]

The primary caretaker[3] in each household was given a demonstration of how to use the product and a pictorial set of instructions; they were also required to demonstrate the ability to successfully treat the water. The treatment process is as follows: flocculant–disinfectant is added to 10 l of water and stirred vigorously for 5 min, allowed to settle, and then decanted through cloth (to remove floating debris) into a storage vessel. The remaining residue in the preparation bucket is then discarded out of the reach of children and animals (most often in latrines). The preparation bucket and decanting cloth are rinsed before reuse. The treated water is ready for use, 30 min after the flocculant–disinfectant is introduced; total time to treat water with PUR was approximately 40 min (including the waiting period).

At enrolment, households in the flocculant–disinfectant group received all of the materials required to use the flocculant–disinfectant appropriately including a bucket and large mixing spoon for preparation, a decanting cloth, a funnel to aid in the transfer from the preparation bucket to the storage container and a storage container with a narrow opening and lid that conforms with CDC safe water storage recommendations (CDC 2000). Each

[2] Sphere Project standards are generally accepted minimum standards for the provision of humanitarian assistance in the disaster and emergency context (Sphere Project 2004).

[3] The primary caretaker was identified by adults in the household as the person who provided the majority of care to dependents, including children, and was primarily responsible for preparation of food, fetching water and other hygiene-related activities.

household received a maximum of 21 flocculation–disinfectant packets per week, and decanting cloths could be exchanged on a semi-monthly basis.

Control group. Households in the control group ($n = 200$) received a funnel and an identical storage container that conformed to CDC recommendations. Households were encouraged to use the funnel and store water in the narrow-opening container as a means of reducing contamination of water during transport and storage.

Weekly visits

Diarrhoea monitoring. All households in the study received weekly diarrhoea monitoring visits during the 12-week study period. Field workers used a standardized questionnaire to record the presence of diarrhoea in each household member; a key informant in the household (usually the female caretaker) provided information for small children or household members who were not present. Diarrhoea was defined as having three or more loose stools in a 24-h period, and a dichotomous measure of diarrhoea within the past week was used as the primary outcome study. All weeks where diarrhoea was reported were classified as prevalent; only cases where diarrhoea was not reported in the preceding week were classified as incident weeks.

Both study sites had health clinics and participants with persistent diarrhoeal symptoms were encouraged to attend. Packets of oral rehydration solution were available from the clinics at no cost; however, field workers also instructed caretakers in each household on the preparation of sugar and salt solution with readily available ingredients.

Sachet distribution. Participants in the intervention group were resupplied with flocculant–disinfectant on a weekly basis. Both empty and unused sachets were counted by field workers during the weekly monitoring visit to assess consumption. Empty sachets were then collected by field workers and households were resupplied so that the household had a total of 21 sachets for use in the coming week.

Chlorine and coliform testing. In addition to the regular weekly monitoring visit, households in the intervention group received unannounced weekly water testing visits. Visits were unscheduled, and field workers were instructed to vary the days and times of visits to each household. During each unannounced visit, field teams checked to see whether the safe water storage container that was provided by the project was being used and tested for both free and total chlorine levels of stored water using CN-66 Free and Total Chlorine Test Kits (Hach Company, Loveland, CO, USA) with a free chlorine detection range of up to 3.5 mg/l.

Both chlorine testing and coliform testing were performed on a weekly basis on nine water sources used by the study population; six water sources were in Last Displaced Camp and three were at Morris Farm. Coliform testing was a qualitative indicator of faecal contamination of drinking water sources. Boreholes were clearly the preferred source of drinking water in both sites (Table 1). All boreholes in Morris Farm ($n = 1$) and in the study areas of Last Displaced

Table 1 Baseline characteristics of households by study group

	Pur ($n = 200$)	Control ($n = 200$)	P-value
Household size	5.7 (SD = 1.5)	5.3 (SD = 1.4)	0.005
Household Head Education (yrs)	3.6 (SD = 4.8)	3.7 (SD = 4.9)	0.538
Primary Caretaker of Children			
Female	198 (99.0%)	199 (99.9%)	0.562
Literacy	47 (23.6%)	47 (23.9%)	0.601
Primary Water Source			
Hand pump	151 (75.4%)	151 (75.5%)	0.977
Well	49 (24.6%)	49 (24.5%)	
Water Handling & Storage			
Narrow opening storage container	105 (53.3%)	121 (61.7%)	0.081
Covered storage container	55 (27.8%)	54 (57.3%)	0.910
Removal by dipping	145 (73.6%)	148 (74.4%)	0.862
Chlorination (ever)	2 (1.0%)	3 (1.5%)	0.657
Sanitary Facilities			
Shared or public latrine	167 (83.5%)	164 (82.4%)	0.791
None	33 (16.5%)	35 (17.6%)	
Diarrhoea Prevalence—all household members (week preceding enrollment)	231 (20.3%)	207 (19.7%)	0.748

Camp ($n = 3$) were tested on a weekly basis for faecal contamination and chlorination. Additionally, wells at Morris Farm ($n = 2$) and Last Displaced Camp ($n = 3$), which were reported as frequently used alternate drinking water sources, were tested. Free and total chlorine levels were obtained using CN-66 Free and Total Chlorine Test Kits. Qualitative (i.e. presence/absence) coliform testing was performed using Pathoscreen™ media (Hach Company); samples were incubated at ambient temperature for 24 h in sterile plastic Whirlpack™ bags (Nasco, Fort Atkinson, WI, USA). The qualitative test was selected as an indicator of water quality because quantitative tests, which provide more specific indications of microbial water quality, were difficult to conduct in the Liberian context where electricity, running water and other basic services required for laboratory-based assessments were not provided. Some basic testing on diarrhoea pathogens was available from several laboratories in the country; however, these were primarily diagnostic services that were not routinely conducted and adequate information on diarrhoea pathogens among the two camp populations was not available from any source.

Statistical analysis

Comparison of baseline characteristics between the two groups was performed with chi-square and *t*-tests. Diarrhoea prevalence was determined by dividing the number of weeks with diarrhoea by the total number of person-weeks of observation. A new (i.e. incident) episode of diarrhoea was classified as a week with diarrhoea only when no diarrhoea was reported in the preceding week. Diarrhoea incidence was calculated by dividing the number of weeks with new diarrhoea episodes by the total number of person-weeks at risk (i.e. weeks of consecutive cases of diarrhoea were excluded because there is no risk for a new episode of diarrhoea). At the household level, a week was classified as an incident week of diarrhoea if any household member reported a new episode of diarrhoea; if no new episode of diarrhoea was reported but diarrhoea persisted in the household, the week was classified as a prevalent week. Descriptive data of diarrhoea incidence and prevalence were calculated at the individual level for the entire study population and children under 5 years of age.

Statistical analysis of the intervention was conducted at the household level, because selection and assignment of participants was at the household level and because households with common food and water sources are likely to have multiple members affected with diarrhoea. Regression models used for adjustment of risk ratios were selected to include predictors with $P < 0.05$ and minimize the residual sum of squares and *F*-statistic. Statistical analysis was performed using SPSS version 12 (Chicago, IL, USA) and STATA version 8 (College Station, TX, USA).

Ethical approval

Ethical approval for the study was granted by the Liberian Ministry of Public Health and by the Johns Hopkins School of Public Health Committee for Human Research.

Results

There were a total of 200 households in each intervention group with 1138 and 1053 individual participants in the flocculant–disinfectant and control groups, respectively. Households in the two participant groups were similar in all indicators measured in the baseline survey except for household size (Table 1); consequently, individual outcomes (diarrhoea) were adjusted for household size. In the baseline survey, which reflected the week preceding study implementation, 20% of the survey population reported diarrhoea.

Of households originally assigned to the flocculant–disinfectant and control groups, only 1% of each group ($n = 2$) did not complete the study. Households that did not complete the study either moved away or had a large portion of their materials (i.e. buckets, water storage containers, mixing spoons) stolen, such that a decision not to replace them was made. Theft of materials was a frequent problem during the study; however, in most cases, arrangements were made for prompt replacements and the household remained enrolled.

Ultimately, 25 944 person-weeks of observation on 2191 individuals were completed, including 8808 person-weeks of observation on children less than 5 years of age. During the study period, diarrhoea was reported in 4.7% of person-weeks in the entire study population and 6.5% of person-weeks in children under 5 years of age. A total of 878 new episodes of diarrhoea were reported during the 12-week monitoring period, of which 347 (41.0%) were in children under 5 years of age. Diarrhoea incidence rates for the complete study population and children under 5 years of age, respectively, were 3.4 (95% CI: 3.2–3.7) and 4.0 (95% CI: 3.6–4.5) cases per 100 person-weeks. Diarrhoea prevalence and incidence were significantly greater in Last Displaced Camp than in Morris Farm ($P < 0.001$ for both comparisons). Respectively, incident and prevalent cases occurred on average 3.1 (95% CI: 2.7–3.7) and 3.1 (95% CI: 2.8–3.6) times more frequently at Last Displaced Camp than at Morris Farm.

Households in the flocculant–disinfectant group had significantly lower diarrhoea incidence and prevalence of diarrhoea than control households. Incident cases of

Table 2 Diarrhoea summary statistics by intervention group

	PUR households		Control households			
	Weeks at risk	Diarrhoea weeks	Weeks at risk	Diarrhoea weeks	Adjusted risk ratio* (95 CI)	Model R^2 value
Incident Weeks						
Overall	2383	66 (2.8%)	2070	595 (28.7%)	3.0 (2.7–3.3)	0.566
Morris Farm	1193	29 (2.4%)	1113	172 (15.5%)	1.4 (1.1–1.8)	0.294
Last Displaced Camp	1190	37 (3.1%)	957	423 (44.2%)	4.5 (4.1–4.8)	0.720
Prevalent Weeks						
Overall	2400	83 (3.5%)	2388	925 (38.7%)	4.4 (4.0–4.8)	0.564
Morris Farm	1200	36 (3.0%)	1188	247 (20.8%)	1.8 (1.8–2.8)	0.310
Last Displaced Camp	1200	47 (3.9%)	1200	678 (56.5%)	6.5 (5.9–7.1)	0.710

*Adjusted for household size and for overall measures, camp of residence.

diarrhoea were reported in 2.8% of weeks by households in the PUR group when compared with 28.7% of weeks among control households ($P < 0.001$). Diarrhoea prevalence was also significantly greater in control households with diarrhoea reported in 38.7% of weeks when compared with only 3.5% of weeks in PUR households ($P < 0.001$). Households in the PUR group had an average of 0.3 incident weeks and 0.4 prevalent weeks during the 12-week monitoring period when compared with 3.2 incident and 4.7 prevalent weeks in control households ($P < 0.001$ for both comparisons). Household diarrhoea incidence, prevalence and risk ratios by survey site are presented in Table 2. The adjusted risk ratios for diarrhoea among control households when compared with intervention households for diarrhoea incidence and prevalence, respectively, were 3.0 (2.7–3.3) and 4.4 (4.0–4.8). Reduction in diarrhoea prevalence and incidence was significantly greater in Last Displaced Camp when compared with Morris Farm; this finding is likely associated with the greater baseline rates of diarrhoea observed in Last Displaced Camp.

Overall, water sources tested positive for coliform contamination in 88% weekly tests with 67–100% of water sources testing positive in any given week. No significant difference in rate of contamination between the two sites was observed with Last Displaced Camp and Morris Farm reporting contamination in 88% and 86% of water source tests, respectively ($P = 0.959$). No significant levels of free or total chlorine were observed in any water source during any time in the trial. Because chlorine was not found in drinking water sources and no control households reported treatment of water, chlorine levels in stored drinking water of control group households were assumed to be zero.

Chlorine levels of stored drinking water were monitored among households in the flocculant–disinfectant group during unannounced weekly visits (Figure 3). A

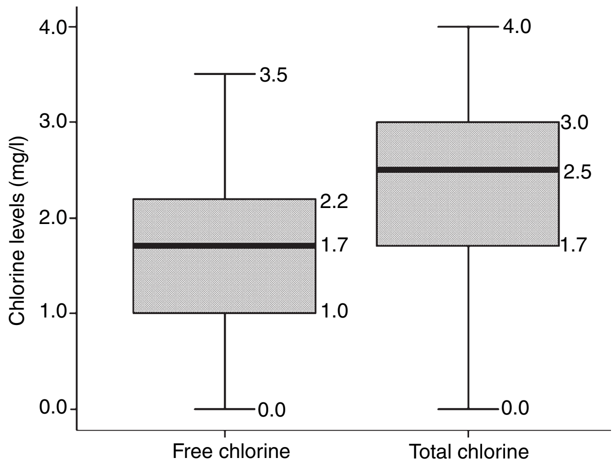


Figure 3 Free and total chlorine levels from unannounced water testing visits to households in the flocculant-disinfectant group ($n = 1551$).

total of 1551 weekly chlorine measures were obtained during the study period. Overall, 95.4% (95% CI: 94.2–96.4) of weekly tests indicated that chlorine was present in the water and that the flocculant–disinfectant product was being used; compliance was lowest during the first week at 90.3%. Mean total and free chlorine levels were 2.30 mg/l (SD = 0.95) and 1.63 ml/l (SD = 0.84), respectively. In 85.0% (95% CI: 83.1–86.8) of weekly observations, free chlorine levels equalled or exceeded the Sphere minimum standard for free residual chlorine (⩾0.5 mg/l) (Sphere 2004). Compliance of residual chlorine levels with Sphere guidelines was lowest during the first week of the trial at 67.7% (95% CI: 54.7–79.1) and then remained above 80% for the remainder of the monitoring period.

Discussion

Point-of-use water treatment with PUR reduced diarrhoea incidence by 90% in intervention households when compared with control households with improved water storage. Diarrhoea prevalence was reduced by 83% when compared with baseline data and 91% when compared with controls with improved water storage. The large magnitude of reduction in diarrhoea incidence is likely the result of extremely high compliance (95.4%) and the resultant levels of free chlorine, which met or exceeded Sphere standards in 85.0% of weekly observations. In addition, the high rate of diarrhoea prevalence at baseline (20%) suggests that diarrhoea may have been epidemic in the camp settings, thus higher reductions in diarrhoea would be expected than other studies in settings where diarrhoea is endemic.

The significant difference in diarrhoea rates between the two camps can potentially be attributed to two factors: Last Displaced Camp had a much larger population than Morris Farm and thus had increased potential for epidemic spread of diarrhoea; and the sanitation situation at Last Displaced Camp was substantially worse than at Morris Farm and direct or indirect contact with faeces is a known transmission route for diarrhoea pathogens (Briscoe 1984). One third of households in Last Displaced Camp reported having no sanitary facilities when compared with 1% in Morris Farm, and residents of Last Displaced Camp were significantly more likely to report that adults and children defecated in public places (when compared with latrines) ($P < 0.05$ for all three comparisons).

A large decline in diarrhoea incidence was observed among controls during the trial period, where the odds of an incident case of diarrhoea were 0.84 (95% CI: 0.82–0.86) less than the preceding week (Figure 4). The decline was attributed to presumed reduction in contamination of water during storage and transport as a result of improved water storage which has been documented in other settings (Roberts *et al.* 2001); a decrease in precipitation as the rainy season subsided; possible sharing or sale of PUR packets by the intervention group to other residents in the camp (including the control group) and possible declines in reporting because of study fatigue (which increased gradually over the study period). Increased prevalence of diarrhoeal disease is frequently associated with the rainy season; while no data are available on the association between diarrhoeal disease morbidity and the rainy season, elevated death rates associated with communicable disease have been documented among Liberian IDPs during the rainy season (July–August) (Valderrama 2002). While the control group remains as a valid comparison group over the trial period, reported percent reductions when compared with baseline data should be interpreted with caution, as it is likely that the natural subsidence of diarrhoea rates with the cessation of the rainy season contributed to the observed reduction.

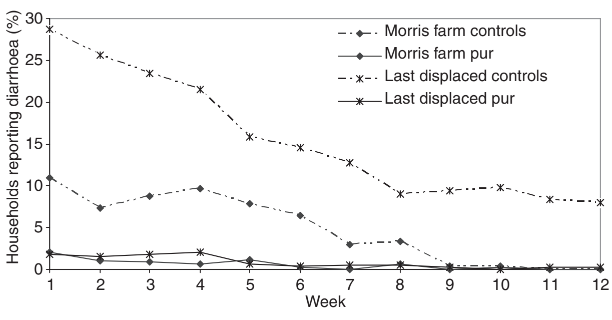


Figure 4 Diarrhoea prevalence by intervention site and group.

Previous studies of the flocculant–disinfectant product have shown treated water to be microbiologically and chemically cleaner and less turbid (Rangel *et al.* 2003; Souter *et al.* 2003; Crump *et al.* 2004). A study in Guatemala reported a 24% reduction in diarrhoea incidence among households receiving the flocculant–disinfectant when compared with controls and noted that the observed reduction was likely influenced by intermittent use of the water treatment product. In the present study, large reductions in diarrhoea incidence and prevalence were attributed to high compliance rates, where water tested positive for chlorine (and was thus treated) in over 95% of visits to intervention households. In focus group discussions, study participants reported the visual improvement in water quality, a preference for the taste of treated water, and the observed reduction in diarrhoea among family members as reasons for compliance. Weekly visits by project staff, the relative ease and rapidness of the water treatment process, and the desire and demand for the product among camp residents are factors that may have contributed to high compliance rates.

Water treatment required less than 10 min of time and there was a 30-min waiting period before water could be consumed. Study participants learned how to treat water in less than 1 h and did not report that treatment was overly time consuming. While the study was time intensive in terms of weekly monitoring and sachet distribution, use of the water treatment product by study participants did not appear to be overly labour or time intensive. No harmful effects of PUR were observed in the present study or reported in previous studies (Rangel *et al.* 2003; Souter *et al.* 2003).

Point-of-use water treatment is frequently used and considered cost-effective in the development context. This method is ideally suited for use in disaster and emergencies because of the frequent unavailability of adequate water and sanitation systems and the large concentrations of populations that are in need of immediate services. Point-of-use water treatment that incorporates flocculation and disinfection is ideal in the acute phases of emergencies when the only available water sources have high levels of turbidity and organic matter such that treatment with sodium hypochlorite is rendered ineffective.

Limitations

A primary limitation of this study was the lack of quantitative measures of water quality. Ideally, faecal coliform or *Escherichia coli* counts of water sources and stored drinking water (in both intervention and control groups) would have been measured in addition to turbidity levels of water from various sources. However, Liberia has significant infrastructure limitations (including that no public services such as water or electricity) and personnel with laboratory training and experience are essentially unavailable. These two constraints led to a decision to assess water quality using methods that were (1) designed for implementation in the field (i.e. no incubation or power supply required) and (2) feasible for implementation by Liberian project staff that did not have extensive formal training in microbiology and/or laboratory techniques.

The diarrhoea reduction observed in the present study is among the largest reported for point-of-use water treatment, indicating that the study may have been subject to reporting biases. A week is a relatively long recall period and it is possible that this influenced study outcomes; previous surveys indicate that diarrhoea prevalence is underreported when week-long recall periods are used (Alam *et al.* 1989; Ramakrishnan *et al.* 1999). Presence or absence of diarrhoea was reported on a daily basis; the analysis plan entailed assessing diarrhoea incidence and prevalence based on person-days; however, because of concerns with accuracy of reporting, the analysis was conducted based on person-weeks in order to reduce the impact of recall bias and subsequent misclassification.

Courtesy bias is another concern where participants may have been likely to underreport diarrhoea cases because they became well acquainted with project staff during the study period and/or because they were receiving the water treatment product at no cost. However, the majority of studies cite compliance as the primary reason for low diarrhoea reduction; unannounced visits to sample stored drinking water for residual chlorine from water treatment found a compliance rate of 95%, making the high observed reduction feasible. One potential explanation for high compliance was the observed visual improvement in water quality and the chlorine taste that was preferred to untreated water.

While findings from the present study indicate a substantial reduction in diarrhoea incidence and prevalence, they should be interpreted with caution in light of the fact that prior studies on point-of-use water treatment reported lesser reductions. While reporting and courtesy bias are potential reasons for the comparatively large reduction that was observed, there are other potential explanations. Diarrhoea in the two camps was epidemic (when compared with endemic in other studies), which resulted in an exaggerated effect of water treatment and storage. Because faecal coliform counts were not determined for water sources in the present study, it is possible that water sources in the present study were substantially more contaminated than those in previous studies that report lower reductions in diarrhoea. There were exceptionally high compliance rates, where stored water in intervention households tested positive for chlorine (an indicator of treatment) in 95% of unannounced visits. Because of the relatively short study period and potential effects of seasonality, the effectiveness of the treatment with the flocculant–disinfectant could be over estimated, which is evident by the decline in diarrhoea rates among the control group over the study period.

Conclusions

Excess morbidity and mortality caused by waterborne diseases during complex emergencies is a widespread phenomenon that is largely preventable. Diarrhoeal diseases result from a variety of factors; however, in the emergency context, insurance of adequate sanitation and water supply (in terms of both quantity and quality) is the primary means for diarrhoea reduction. In this study, a point-of-use flocculant–disinfectant significantly reduced the incidence and prevalence of diarrhoeal disease among households residing in camp settings in the emergency context. Further research on point-of-use water treatment methods such as flocculant–disinfectant, and their role in various stages and types of emergencies will help to determine the potential of point-of-use water treatment and household level interventions in the emergency context.

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Conflict of interest

The study was funded in part by Procter and Gamble that manufactures and markets PUR. Procter and Gamble was not involved in the design or execution of the study or the analysis or write up of results.

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Traitement des points d'eau et réductions des diarrhées en cas d'urgence: une étude d'efficacité au Libéria

Les maladies transmissibles sont un problème majeur parmi les populations sinistrées et en conflits résidants dans des camps de réfugiés. Dans une phase aiguë d'urgence, les diarrhées sont responsables de plus de 40% de morts parmi les résidents d'un camp. Les technologies de traitement des eaux actuels sont clairement limitées et peu de produit sont efficaces dans le traitement des eaux torpides. Nous décrivons les résultats d'une étude d'efficacité de 12 semaines sur le traitement des points d'eaux avec un désinfectant floculant parmi 400 foyers dans des camps de populations déplacées à Monrovia, Libéria. Dans les foyers d'intervention, le traitement des points d'eaux avec le désinfectant floculant et l'amélioration du stockage réduisaient l'incidence des diarrhées de 90% et la prévalence de 83%, en comparaison aux foyers contrôles où seule l'amélioration du stockage de l'eau était réalisée. Parmi le groupe d'intervention, les niveaux de chlore résiduels atteignaient ou excédaient les Sphere standards dans 85% (IC 95% [83.1; 86.8]) des cas avec un taux de compliance de 95%.

mots clefs Traitement des points d'eaux, traitement des eaux domestiques, désinfectant floculant, Libéria, diarrhées

Tratamiento de puntos de agua y reducción de diarrea en zonas de emergencia: una prueba de efectividad en Liberia

Las enfermedades transmisibles son una preocupación particular en poblaciones afectadas por conflictos o desastres que residen en campamentos. En la fase más aguda de la emergencia, las enfermedades diarreicas han sido responsables por más del 40% de los fallecimientos entre los residentes de los campamentos. Existen claras limitaciones en las actuales tecnologías de tratamiento del agua, y pocos productos son capaces de tratar el agua turbia. Describimos las conclusiones de un estudio de efectividad de 12 semanas de tratamiento de puntos de agua con desinfectante floculante en 400 grupos familiares en campamentos para población desplazada en Monrovia, Liberia. En los grupos familiares intervenidos, el tratamiento del punto de agua con desinfectante floculante más el mejoramiento del almacenamiento redujo la incidencia de diarrea en un 90%, y la prevalencia en un 83%, comparado con grupos familiares controlados con solamente el almacenamiento mejorado. Dentro del grupo de intervención, los niveles residuales de cloro alcanzaron o excedieron los estándares Esfera en 85% (95% CI: 83.1–86.8) de las observaciones con una tasa de cumplimiento de un 95%.

palabras clave tratamiento del agua en el punto de utilización, tratamiento del agua en el grupo familiar, desinfectante-floculante, Liberia, diarrea