

Evaluation of pot-chlorination of wells during a cholera outbreak, Bissau, Guinea-Bissau, 2008

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ABSTRACT

We evaluated the ability of UNICEF-designed pot-chlorinators to achieve recommended free residual chlorine (FRC) levels in well water in Bissau, Guinea-Bissau, during a cholera outbreak. Thirty wells were randomly selected from six neighbourhoods. Pot-chlorinators – perforated plastic bottles filled with gravel, sand and calcium hypochlorite granules – were placed in each well. FRC was measured before and 24, 48 and 72 h after placement and compared with World Health Organization (WHO)-recommended levels of ≥ 1 mg L⁻¹ for well water during cholera outbreaks and 0.2–5 mg L⁻¹ in non-outbreak settings. Presence of well covers, distance from wells to latrines, and rainfall were noted. Complete post-chlorination data were collected from 26 wells. At baseline, no wells had FRC > 0.09 mg L⁻¹. At 24, 48 and 72 h post-chlorination, 4 (15%), 1 (4%) and 0 wells had FRC ≥ 1 mg L⁻¹ and 16 (62%), 4 (15%) and 1 (4%) wells had FRC between 0.2 and 5 mg L⁻¹, respectively. Several families reported discontinuing household water chlorination after wells were treated with pot-chlorinators. Pot-chlorinators failed to achieve WHO-recommended FRC levels in well water during a cholera outbreak, and conveyed a false sense of security to local residents. Pot-chlorination should be discouraged and alternative approaches to well-water disinfection promoted.

Key words | cholera, pot-chlorinators, *Vibrio cholerae*, well chlorination

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INTRODUCTION

Cholera remains an important public health issue in much of Africa. In 2008, 94% of the 190,130 cholera cases reported worldwide occurred in sub-Saharan Africa (WHO 2009a). In the West African country of Guinea-Bissau, cholera is endemic. Since 1994, the country has suffered five nationwide outbreaks, each claiming hundreds to thousands of lives (WHO 2008).

The most recent cholera outbreak in Guinea-Bissau occurred between May and November 2008. The outbreak spread to seven of eight political regions of the country with a total of 14,323 reported cases and 225 deaths (WHO 2009a); 66% of cases occurred in the capital city of Bissau, home to approximately 20% of the country's almost 1.6 million residents (Encyclopedia of the Nations 2007; CIA 2011).

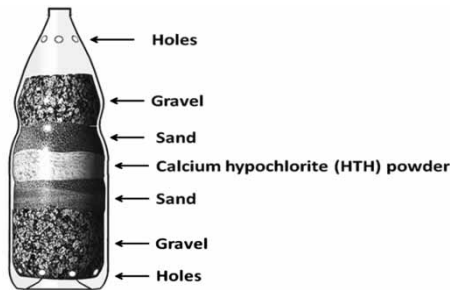
Since most cholera outbreaks are propagated via faecally contaminated water (Griffith *et al.* 2006), ensuring a safe drinking water supply is essential for outbreak prevention and control. According to the WHO, 57% of the total population of Guinea-Bissau and 82% of the urban population has sustainable access to improved drinking water sources, such as tap water or a borehole, tubewell or protected well water (WHO 2009b). However, only 20% of Bissau residents have access to municipal tap water (Nzirorera 2008), which is not chlorinated. Most of the Bissau population obtains water for drinking and other uses from approximately 3,000 wells, many of which are hand-dug and shallow. Toxigenic *Vibrio cholerae* O1, the cause of the current cholera pandemic, survives as a free-living organism in brackish rivers and coastal water (Reidl & Klose 2002). In cities such as Bissau, located near the deltas of major river systems, contaminated natural waters can easily infiltrate shallow riverine wells. A recent evaluation of nine wells and three taps in one Bissau neighbourhood found $>1 \times 10^5$ CFU (colony forming units) mL^{-1} of total coliforms, *Escherichia coli* and *Enterococcus faecalis* in all 12 water sources (Colombatti *et al.* 2009).

Vibrio cholerae is easily inactivated by chlorine. The effectiveness of chlorine at inactivating different pathogens is expressed by the contact time (CT) factor, which is the

product of the disinfection concentration and time of contact with the pathogen; a higher CT factor indicates higher resistance to chlorine and a lower CT factor indicates lower resistance to chlorine. The CT factor for typical *Vibrio cholerae* is $<0.5 \text{ mg L}^{-1}\text{-min}$ (CDC 2008); therefore, water chlorination is an effective method of cholera control if adequate free residual chlorine (FRC) levels are obtained and maintained. In non-epidemic settings, WHO water chlorination guidelines recommend the maintenance of FRC levels $\geq 0.2\text{--}0.5 \text{ mg L}^{-1}$ for infrastructure water; however, in cholera epidemics, WHO recommends FRC levels $\geq 1 \text{ mg L}^{-1}$ for well water (WHO 1997). In all settings, FRC levels should not exceed a maximum guideline value of 5 mg L^{-1} (WHO 1997).

In Bissau, where shallow wells are a primary source of drinking water, achieving consistent chlorination is challenging. Although several methods for chlorinating wells have been described, few scientific studies have demonstrated effective, sustained disinfection in emergency or outbreak settings in developing countries. Shock or spot chlorination is commonly used; in this method, a calculated bolus of liquid chlorine is introduced into a well and the well is closed for 24 h or pumped after several hours to achieve an acceptable FRC level. However, studies measuring thermotolerant coliform levels (Luby *et al.* 2006) and FRC levels (Rowe *et al.* 1998) have shown highly variable and short-lived FRC levels in treated wells with little improvement in microbiological water quality.

Pot-chlorination, another widely used well-disinfection method, is designed to provide a more constant FRC level over a longer period of time. Pot-chlorinators are pierced containers (clay pots, plastic bottles or jerry cans) filled with layers of calcium high test hypochlorite (HTH) powder, gravel and sand, and suspended in a well (Figure 1). The intention of the pot-chlorinator is to provide a slow diffusion of chlorine into the water in order to maintain a consistent FRC concentration sufficient to inactivate *V. cholerae*. Many resources describe the construction and use of pot-chlorinators for well disinfection (Cairncross & Feachem 1993; Feachem *et al.* 1977; Garandeanu 2004), but few studies have evaluated their effectiveness.



Plastic Bottle Chlorinator

Figure 1 | Example of plastic bottle chlorinator.

In an effort to curb the spread of the cholera outbreak, the Bissau Department of Water and Sanitation (BDWS), in collaboration with UNICEF, began a project in mid-August 2008 to disinfect municipal wells in affected Bissau neighbourhoods using hand-made pot-chlorinators. Pot-chlorinators made from 1.5 L plastic bottles were suspended in approximately 600 wells in 10 Bissau neighbourhoods. A monitoring plan had been developed, but data were inconsistently collected and unsuitable for analysis.

Therefore, at the request of the Guinea-Bissau Ministry of Health and BDWS, we conducted an independent prospective evaluation to determine whether adequate free residual chlorine (FRC) levels were achieved and sustained in Bissau wells after placement of hand-made pot-chlorinators.

METHODS

Well selection

Six neighbourhoods were randomly selected from a list of 22 Bissau neighbourhoods most affected by cholera. In each neighbourhood, a team drove to a central car-accessible location and a team member familiar with the neighbourhood chose a convenience sample of five wells for evaluation. A total of 30 wells were evaluated.

Bottle chlorinator assembly

The protocol used for the UNICEF/BDWS well-chlorination project was followed for constructing the pot-chlorinators. A 1.5-L plastic bottle was rinsed with water.

Since most teams in the UNICEF/BDWS well-chlorination project used 20 holes per bottle (five in the bottom, two rows of seven circling the lower portion of the bottle, and one 'air hole' near the bottle neck), this was chosen as the standard for the evaluation. Holes were made using a nail, for a hole size of approximately 3–4 mm. The bottom third of the bottle was filled with washed gravel and the second third with washed sand.

Calculation of well water volume

Well diameter was measured using a measuring tape and divided by two to calculate well radius (r). To measure water depth in each well (h), a piece of rope with a weight attached was dropped into the well until it reached the bottom; a second piece of rope with an empty soda can was lowered into the well until the can floated on top of the water. Both pieces of rope were then removed simultaneously from the well and the distance between the ends of the ropes was used as the well water depth. Well water volume (V) was then calculated using the formula: $V(\text{m}^3) = \pi \times r^2 \times h$

Calculation of calcium hypochlorite added to bottle chlorinator

The calcium hypochlorite dosage used in the UNICEF/BDWS project was followed: 15 g of Niclon 70-G granular calcium hypochlorite (Tohoku Tosoh Chemical Co., Ltd) per 1 m³ (1,000 L) of well water. Since a scale was not available in the field, it was estimated that 1 mL of calcium hypochlorite granules equalled 1 g of granules in weight; granules were measured using a graduated 20 mL measuring cup. The amount of calcium hypochlorite required for each well was calculated and added to the bottle on top of the layer of sand; the calcium hypochlorite was then covered with an additional layer of sand and the bottle was capped. A rope was tied around the bottle neck and the bottle was lowered upright into the well until it was submerged; the end of the rope was secured to the exterior of the well.

A sample of Niclon 70-G granular calcium hypochlorite granules was evaluated at the Centers for Disease Control and Prevention following the study; one millilitre of granules

weighed 0.9 g and the actual chlorine content by weight was 73%.

Data collection

Free and total chlorine levels were measured using a LaMotte™ 1200-CL chlorimeter calibrated with non-expired standards before data collection. Water pH was measured using a Taylor Pool and Spa Water Test kit™. Turbidity was assessed using a simple visual scale; if it was possible to clearly see the bottom of a 20-L bucket full of well water, the water was considered clear, if not, the water was considered turbid. Before placement of the bottle chlorinator, baseline free and total chlorine and pH were measured at each well; water turbidity was also noted. Next, well radius, water height and volume, and the amount of calcium hypochlorite to be added to the bottle were recorded; the calculated calcium hypochlorite amount was added to the bottle and the bottle was submerged in the well. Households were told to wait 24 h after the bottle placement before drawing well water. Wells were revisited 1–3 days following bottle chlorinator placement, and free and total chlorine and pH were measured. At each visit, water turbidity, the presence or absence of a well cover and whether the bottle was still in the well were noted, and local residents were asked if it had rained overnight.

Data analysis

Data were entered into Microsoft Access (Microsoft 2003, Redmond, Washington) and analysed using SAS (SAS Corporation, Cary, NC, USA) and Excel 2003.

RESULTS

A total of 30 wells were evaluated at baseline and approximately 24 (mean = 20 ± 1.7 h, range = 19–23 h), 48 (mean = 45 ± 2 h, range = 43–48 h) and 72 (mean = 74 ± 1.3 h, range = 72–77 h) hours following placement of a pot-chlorinator. One well was determined to be a cement cistern with water pumped in from a well; since it was a storage system and not a well, it was excluded from the study.

A total of three bottles were removed from wells by local residents for unknown reasons, one on each day of observation, leaving a total of 26 wells with complete post-chlorination data; only the 26 wells with complete data were used for analysis.

Well and environment description

All wells in the study were shallow, hand-dug, open wells; several had concrete linings. Water depths ranged from 0.7 to 4.95 m (mean = 2.2 ± 1.19 m); 15 (58%) wells had water depths <2 m. Water volumes ranged from 0.6 to 8.0 m³ (mean = 2.62 ± 1.99 m³); 19 (73%) wells had a water volume <3 m³. Among the 26 wells, 24 (92%) had a latrine <30 m from the well (Table 1). Seven (28%) wells were covered with a lid at baseline. At 24, 48 and 72 h post-chlorination, 21 (81%), 11 (42%) and 5 (19%) wells were covered with a lid, respectively; only four (15%) wells were covered at all visits. No rain fell on the first night following placement of the chlorinators; however, heavy rains fell on the second night at all locations, and on the third night at six (23%) locations.

Turbidity and pH

Two wells (8%) at baseline and one well (4%) 24 h post-chlorination had turbid water. Turbid water was observed in four wells (15%) 48 h post-chlorination, after a night of heavy rains at all well locations; two of these wells were protected with a lid at the time of observation. Two wells (8%) had turbid water 72 h post-chlorination; neither well location had received rain overnight. Only two wells were turbid for two or more consecutive days. All wells had a pH <8 at baseline (mean = 6.5 ± 0.08) and at 24, 48 and 72 h post-chlorination (mean = 6.5 ± 0.28 , 6.5 ± 0.22 , 6.7 ± 0.46 , respectively).

FRC levels compared with WHO guidelines for non-outbreak (FRC level between 0.2–5.0 mg L⁻¹) and for cholera outbreak settings (FRC level ≥ 1.0 mg L⁻¹)

At baseline, all wells (100%) had baseline FRC levels below the detection limit (BDL) of ≤ 0.1 mg L⁻¹. Approximately 24 h post-chlorination, FRC in wells ranged from BDL to

Table 1 | Characteristics of study wells and well environment, Bissau, Guinea-Bissau, September 2008 ($n = 26$)

Well #	Latrine >30 m from well	Well height (m)	Well volume (m ³)	Baseline FRC (mg L ⁻¹)	24 h post-bottle placement FRC (mg L ⁻¹)	48 h post-bottle placement FRC (mg L ⁻¹)	72 h post-bottle placement FRC (mg L ⁻¹)
1	Yes	1.7	1.79	BDL	0.18	BDL	0.13
2	No	2.26	2.55	BDL	BDL	BDL	BDL
3	Yes	2.28	2.75	BDL	0.89	0.10	BDL
4	Yes	1.5	1.42	BDL	BDL	BDL	BDL
5	Yes	1.76	2.33	BDL	0.33	BDL	BDL
6	Yes	1.5	1.75	BDL	0.54	0.10	BDL
7	Yes	3.4	6.5	BDL	0.56	0.40	BDL
8	Yes	2.93	3.48	BDL	1.15	BDL	0.21
9	Yes	3.9	6	BDL	0.55	0.16	0.16
10	Yes	3.74	1.48	BDL	BDL	BDL	BDL
11	Yes	4.25	6.17	BDL	2.06	0.48	0.10
12	Yes	4.5	8	BDL	0.85	0.18	0.14
13	Yes	4.95	4.7	BDL	1.02	0.15	0.12
14	Yes	1.33	0.6	BDL	0.24	BDL	BDL
15	Yes	1.67	1.82	BDL	6.00	1.80	0.12
16	Yes	1.3	2.17	BDL	0.21	BDL	BDL
17	No	1.34	1.22	BDL	BDL	BDL	BDL
18	Yes	1.6	1.63	BDL	0.39	BDL	BDL
19	Yes	1.2	1.14	BDL	BDL	BDL	BDL
20	Yes	2.29	1.46	BDL	0.91	BDL	BDL
21	Yes	1.73	1.76	BDL	0.16	BDL	BDL
22	Yes	0.7	0.93	BDL	0.33	BDL	BDL
23	Yes	1.58	1.5	BDL	0.44	0.11	BDL
24	Yes	2.51	3	BDL	0.32	0.13	BDL
25	Yes	1.1	1.2	BDL	BDL	BDL	BDL
26	Yes	0.74	0.8	BDL	BDL	0.32	0.10

FRC, free residual chlorine; BDL, below the detection limit.

6.0 mg L⁻¹ (mean = 0.67 ± 1.18 mg L⁻¹). Sixteen (62%) of 26 wells had FRC levels between 0.2 and 5.0 mg L⁻¹; the FRC level was <0.2 mg L⁻¹ in nine (35%) wells and >5.0 mg L⁻¹ in one well. Approximately 48 h post-chlorination, FRC levels in wells ranged from BDL to 1.8 mg L⁻¹ (mean = 0.18 ± 0.35 mg L⁻¹). Four (15%) wells had FRC levels between 0.2 and 5.0 mg L⁻¹ and the remaining FRC levels were <0.2 mg L⁻¹. After approximately 72 h, FRC levels in wells ranged from BDL to 0.21 mg L⁻¹ (mean = 0.07 ± 0.05 mg L⁻¹). Only one (4%) well had an FRC level ≥0.2 mg L⁻¹ (Table 1, Figure 2).

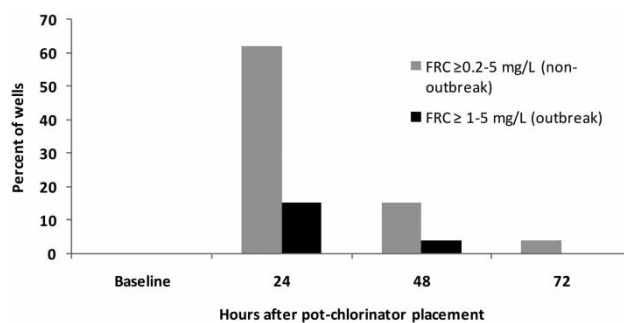


Figure 2 | Summary of free residual chlorine (FRC) levels by days after pot-chlorinator placement.

Approximately 24 h post-chlorination, four (15%) wells had FRC levels $\geq 1.0 \text{ mg L}^{-1}$; one of these wells had an FRC level that exceeded 5.0 mg L^{-1} . Only this well (4%) had an FRC level $\geq 1.0 \text{ mg L}^{-1}$ at 48 h post-chlorination. At 72 h post-chlorination, no wells had FRC levels $\geq 1.0 \text{ mg L}^{-1}$ (Table 1, Figure 2).

DISCUSSION

We found this method of pot-chlorination ineffective at achieving and sustaining FRC levels recommended for well water during a cholera outbreak. Recommended FRC levels for a cholera outbreak were sustained for 24 h in only four (15%) of 26 wells and for 48 h in only one well (4%) in which an FRC level exceeding WHO guidelines had been documented at 24 h. Our study occurred during a cholera outbreak, but we noted that this method of pot-chlorination also failed to maintain FRC levels recommended for non-outbreak settings. Over half of the wells had FRC levels within the recommended range for non-outbreak settings at 24 h post-chlorination; however, appropriate levels were maintained for 48 h in only 15% of wells, thus providing only transient protection.

Effective well chlorination depends on several factors, including water quality and quantity. Controlling these factors is difficult in unsealed wells in resource-poor settings; thus, pot-chlorination is not effective or practical for long-term maintenance of FRC levels in these conditions. High levels of organic material in water decrease water quality and increase chlorine demand. Organic material may be introduced into open wells via contaminated buckets and from the well structure itself. Shallow wells located $<30 \text{ m}$ from latrines – most wells in our study – are at particularly high risk for contamination with organic material. Sand and gravel from the pot-chlorinators themselves may contaminate well water and increase chlorine demand. In addition, sand and gravel may increase water turbidity, which adversely affects the efficiency of disinfection. The pH of water also affects well chlorination; water with a higher pH (usually >8) requires a longer chlorine contact time or a higher FRC at the end of the contact time for adequate disinfection (WHO 2006). In our study all wells had an appropriate pH for effective chlorine disinfection.

Rainfall, especially in open wells, and abstraction rate may alter chlorine demand by changing well water quantity and quality. Since it is often difficult to accurately measure both chlorine demand and well volume in resource-poor settings, frequent monitoring and possibly replacement or replenishment of pot-chlorinators may be necessary to maintain appropriate chlorine levels in wells.

During the cholera outbreak in Bissau, frequent monitoring and replacement or replenishment of pot-chlorinators to maintain adequate FRC levels would not have been practical or cost-effective. Our study employed two teams of three people, who conducted these measurements over three 5-h days. Based on the amount of time each team spent in the field testing the wells, we estimate that if all 3,000 wells in Bissau were treated with this method and monitored daily, 600 people (200 teams of three) working 5 h per day would be required. In our study, each completed bottle cost approximately US\$3, so the total cost for bottles to treat 3,000 wells would equal \$9,000. Additional costs would be required for chlorimeter materials, chlorine to maintain FRC levels, and local transportation. In resource-poor countries, the cost-effectiveness of such an intervention is questionable.

In addition, pot-chlorination may be unintentionally detrimental to health, either because initial FRC levels may exceed WHO guidelines, or because it may convey a false sense of security to residents. Anecdotally, in a separate household survey conducted in Bissau during this cholera outbreak, several families voluntarily reported discontinuing household water treatment with chlorine after their wells were treated with pot-chlorinators by the UNICEF/BDWS project; these families believed the pot-chlorinators adequately disinfected their well water and, therefore, household water treatment was unnecessary. Because pot-chlorination was not shown to be effective in achieving desired levels of FRC in the majority of wells for more than one day, this project may have paradoxically increased the risk of cholera in some households.

Three bottles were removed from wells by local residents during the study. Based on comments from other local residents, it appeared that the removal was not due to objections to the pot-chlorinators, but rather because residents desired the nylon rope used to hang the bottles in the wells. As the team removed the remaining bottles from wells

at the completion of the study, local residents also asked to keep the rope. The removal of pot-chlorinators by community members highlights an additional limitation of this method; monitoring wells to ensure that bottles are still in place and educating the community to leave bottles in the well is necessary.

We are aware of only one study evaluating locally made pot-chlorinators for well disinfection, in peri-urban Monrovia, Liberia, in 2004. Pot-chlorinators made out of 4-L plastic jerrycans, pierced with two 3 mm holes at the top and bottom, and filled with layers of gravel, sand and 750 g of 65% calcium hypochlorite granules were tested in 10 public wells (two lined wells with hand pumps and eight unlined wells, five of which were covered) for 6 days. Only five wells had FRC levels measured for all 6 days. Although all of the wells with complete data had FRC levels $>1 \text{ mg L}^{-1}$ for all observation days, 80% of these wells had an FRC level $>10 \text{ mg L}^{-1}$ on two or more observation days, well above the WHO recommended threshold. In addition, several wells had FRC levels tested 2 or 3 times in a day and FRC levels were found to vary widely between morning and evening tests. For example, in one well the FRC level was $>10 \text{ mg L}^{-1}$ at 10.30 a.m., 1.4 mg L^{-1} at 11.45 a.m., and 0.6 mg L^{-1} at 7.00 p.m. Based on these findings, two modified pot-chlorinator designs, each with different proportions of sand and gravel, smaller amounts of calcium hypochlorite granules and smaller-sized pierced holes, were evaluated in 4 and 6 wells. Between 50 and 100% of wells with one of the modified designs had an FRC level $>1 \text{ mg L}^{-1}$ for two or more observation days and no wells had an FRC level $>10 \text{ mg L}^{-1}$; however, wide variation in FRC levels were again seen in several wells within a 24-h period. The pot-chlorinators in this study each cost between \$2 and \$6 (Garandeanu 2004). Thus, similar to our results, the pot-chlorination method in this study did not provide consistent or appropriate FRC levels, and required frequent and labour-intensive monitoring.

Two published studies have evaluated a modified pot-chlorinator using locally pressed HTH tablets in place of granules; the tablets are thought to provide a slow, continuous diffusion of chlorine (Libessart & Hammache 2000; Garandeanu *et al.* 2006). One study reported FRC levels sustained between 0.2 and 1 mg L^{-1} for 3–6 days in wells

treated with this method (Garandeanu *et al.* 2006). However, FRC levels did not meet the WHO guidelines for a cholera outbreak. In both studies, the tablets were made in a manual press, raising questions about the stability of the tablets and the speed and constancy of the rate at which they dissolve. Dosing for different well volumes may also be difficult with chlorine tablets. More rigorous field studies are needed to evaluate well chlorination with locally pressed HTH tablets.

Based on our study findings, alternative approaches to well disinfection during cholera outbreaks need to be considered. The use of pot-chlorination should be discouraged unless FRC levels can be monitored daily and additional chlorine added when needed. One alternative option is to pump well water into a cistern with a known volume; the cistern water can then be chlorinated and dispensed through a tap. This method would reduce variability of FRC levels over time and the need for monitoring the water to ensure that the FRC level was maintained.

Another alternative approach is treating water at the source via bucket chlorination, in which water is disinfected as soon as it is collected, either by a person dispensing chlorine, or a chlorine dispenser located at each well. If a standard-sized container is used, chlorine dosing is simple and quick. One disadvantage is that it takes 30 min for the chlorine to disinfect the water so the method must be accompanied by education. Preliminary results from a study in rural Kenya suggest that the chlorine dispensers are well accepted by community members and are between a quarter and a third of the cost of individual bottles of the same product for household use (Null *et al.* 2009).

Point-of-use chlorination at the source, or at the household, is recognized and validated in the literature as an effective drinking water treatment method in many settings, including cholera outbreaks and other emergencies (Mintz *et al.* 2001; Mong *et al.* 2001; Lantagne 2008). Results from several studies suggest that it is possible to quickly scale up point-of-use chlorination interventions during emergencies (Dunston *et al.* 2001; Mong *et al.* 2001).

This study had several limitations. Since we did not have a turbidimeter or pH meter, we were unable to precisely calculate nephelometric turbidity units and pH levels and therefore assess whether turbidity or pH affected disinfection. We were also unable to measure the water

abstraction rate and amount of rainfall at each well, both of which can affect chlorine demand, well volume and FRC levels. Due to time and resource constraints we were not able to measure levels of indicator bacteria or evaluate the viability of *Vibrio cholerae* in water samples from the study wells. Future studies including these measurements should be considered as they could provide useful data about the effect of chlorination on bacteriological water quality.

CONCLUSIONS

Based on our findings, pot-chlorinators were ineffective, costly and impractical for well disinfection, and their use should be discouraged. Instead, efforts should focus on promoting community water disinfection methods that have been validated in the literature. Further research into novel methods for well disinfection and cost-effective ways to quickly scale up these methods in emergency settings is needed.

DISCLAIMER

Use of trade names and commercial sources is for identification only and does not imply endorsement by the Office of Workforce and Career Development, Centers for Disease Control and Prevention, or the US Department of Health and Human Services. The findings and conclusions in this report are those of the author and do not necessarily represent the views of the Department of Health and Human Services or the Centers for Disease Control and Prevention.

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