Learning from water treatment and hygiene interventions in response to a hepatitis E outbreak in an open setting in Chad

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ABSTRACT

In September 2016, Médecins Sans Frontières responded to a hepatitis E (HEV) outbreak in Chad by implementing water treatment and hygiene interventions. To evaluate the coverage and use of these interventions, we conducted a cross-sectional study in the community. Our results showed that 99% of households interviewed had received a hygiene kit from us, aimed at improving water handling practice and personal hygiene and almost all respondents had heard messages about preventing jaundice and handwashing. Acceptance of chlorination of drinking water was also very high, although at the time of interview, we were only able to measure a safe free residual chlorine level (free chlorine residual (FRC) $\geq$0.2 mg/L) in 43% of households. Households which had refilled water containers within the last 18 hours, had sourced water from private wells or had poured water into a previously empty container, were all more likely to have a safe FRC level. In this open setting, we were able to achieve high coverage for chlorination, hygiene messaging and hygiene kit ownership; however, a review of our technical practice is needed in order to maintain safe FRC levels in drinking water in households, particularly when water is collected from multiple sources, stored and mixed with older water.

Key words | drinking water, HEV, hygiene promotion, outbreak interventions, water treatment

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BACKGROUND

In September 2016, four pregnant women with acute jaundice syndrome (AJS) were admitted to a Médecins Sans Frontières Holland (MSF) supported hospital in Am Timan, Chad, two of whom died. Rapid diagnostic testing suggested infection with hepatitis E virus (HEV), which was confirmed by serologic testing in a Dutch reference laboratory. Many similar cases of AJS were subsequently detected in the community (Spina *et al.* 2017). HEV was thought to be endemic in the region, however the baseline immunity against this disease in Am Timan was unknown. The last documented outbreak in Chad was in 2004, in two refugee camps among Sudanese refugees (Guerrero-Latorre *et al.* 2011).

The town of Am Timan in the south-east of Chad, where the outbreak occurred, is shown in Figure 1.

MSF, at the request of the Ministry of Health, Chad (MoH), launched a rapid and large-scale outbreak response, including water and hygiene interventions as well as active

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Figure 1 | Area map of Chad.

community-based surveillance and case management. The interventions comprised three key activities: chlorination of water supplies, hygiene promotion and hygiene kit distribution. A sanitation intervention was considered but deprioritised due to the scale of other needs and limited resources; however, promotion of use of latrines was included in the hygiene promotion activity.

At the time of the study, controlled bucket chlorination (concentrated chlorine solution dispensed directly into water collection containers) was being implemented at 70 water points within the town catchment area. These water points (classifed in our survey as 'private wells') comprised 36 boreholes connected to open concrete tanks, 31 hand pumps, 2 foot pumps and 1 MSF installed jetted well at the riverside. MSF also supported the repair of two automatic chlorine dosing systems for the town water networks. Chlorine was dosed, according to emergency drinking water guidelines (MSF 2010; WHO 2014), to systematically achieve a free chlorine residual (FRC) at the point of collection of $\geq$0.5 mg/L after 30 minutes contact time. The chlorine dosage at each water point was checked on a daily basis to ensure consistency.

Outreach workers conducted hygiene promotion at water points and by visiting all households at least biweekly. During the first week of December 2016, one hygiene kit was distributed to each household in the town ($n =$ 10,567). The kit included one jerry can, three months' supply of soap (250 g/person/month), one bucket and two plastic goblets. A hygiene promotion campaign focusing on handwashing with soap was implemented in parallel to the distribution.

In January 2017, we conducted a cross-sectional study to estimate the coverage of hygiene promotion in the community, use of the hygiene kit and effectiveness of the water treatment programme. We sought to identify any gaps in the outbreak response and to provide further insight into the challenges of implementing these interventions during a hepatitis E outbreak in an open setting.

METHODS

Sampling strategy and sample size

The study population was females over the age of 18 years residing in Am Timan. We selected a simple random sample of households from a comprehensive list compiled during community outreach activities, where each household was assigned a block and house number through systematic door-to-door visits. Surveyors visited the selected households and interviewed a woman who self-identified as being responsible for water collection. Women were chosen as the respondent, since they are most involved with water handling and hygiene practices within the household in Chadian culture. If no respondent was available within a given household, the closest neighbouring household was selected. This was repeated a second time if necessary.

It was estimated that 395 households were needed to detect 50% coverage of households with a detectable FRC level (0.1 mg/L) in stored water at a precision of $\pm$0.05, with a design effect of 1, 2% non-response and an estimated town population of 50,000. This sample size was chosen in order to be representative of the whole community.

Data collection

Data was collected during the period 27 December 2016 to 8 January 2017, by a team of nine surveyors who were not affiliated with the water and hygiene activities. Surveyors interviewed respondents in their homes using a structured questionnaire with spot check observations. Questions comprised: demographics (family size and composition), recall of HEV prevention methods, hygiene kit items (presence and use) and water handling practice. Furthermore, respondents were asked whether their water had been chlorinated and the reason why if they had refused; when was the last time they collected water and the level in the storage container when they added new water. Surveyors also estimated water storage container size and measured the FRC level in the container identified by respondents as most frequently used for drinking water. This was done with hand-held pool testers following the manufacturer's instructions (Palintest®, UK).

The questionnaire was developed in written French, since Chadian Arabic is a verbal dialect and cannot be easily written. A translation into verbal Arabic was done together with the survey team through consensus to ensure consistency. Data entry was performed by a clerk in the field using Microsoft Excel and checks were performed to ensure accuracy.

Statistical analysis

We calculated medians and ranges for numerical variables and prevalence (proportions) with 95% confidence intervals (95% CI) for categorical variables. We calculated prevalence ratios (PRs) and respective 95% CIs using Poisson regression to examine associations for having safe FRC levels (defined as $\geq$0.2 mg/L) with the amount of water in the storage container when it was refilled, the time since last water collection and the most commonly used source of water. All analyses were carried out using R statistical programming software version 3.3.2 (R Foundation for Statistical Computing, Vienna, Austria).

ETHICS

The MSF Medical Director (Amsterdam, The Netherlands) exempted this study from full review in accordance with the MSF Ethical Review Board guidelines, as it represented routine monitoring and evaluation work where respondents were not exposed to risks. Verbal consent to participate was obtained from all respondents in their native language prior to beginning the questionnaire or conducting water testing. All responses were treated as anonymous and confidential. Households with FRC below the safe level in their stored drinking water were informed about safe water storage and handling practices. Permission to perform the study was granted by the MoH.

RESULTS

Demographics

Three of the 395 households responding to the survey were excluded due to missing FRC data; therefore, 392 households were included in the analysis. The median household size was seven people (range 1–33) and the median number of children <5 years of age per household was two (range 0–10).

Hygiene promotion

MSF's hygiene and health promotion messages related to HEV reached 388 (99%, 95% CI 97–100) households. The most common dissemination method was a household visit by an outreach worker (90%, 95% CI 86–93), followed by radio (56%, 51–61), contact at water points (45%, 40–50) and the mosque (9%, 6.4–12). Two hundred and seventy-five (70%, 95% CI 65–75) respondents reported hearing messages through more than one method.

The messages most frequently recalled by the respondents related to handwashing before preparing food (96%, 95% CI 94–98) and after using the toilet (89%, 95% CI 85–92) (Table 1).

Of all respondents, 185 (47%, 95% CI 42–52), 106 (27%, 95% CI 23–32) and 83 (21%, 95% CI 17–26) respondents recalled all key messages related to each of three health promotion subjects: handwashing, chlorination and HEV awareness, respectively (Table 1).

Table 1 | Reported frequency of messaging heard in Am Timan ($n = 392$)

	Frequency (n)	%	95% CI
Messages on handwashing			
Importance of washing hands after using the toilet	349	89	85–92
Importance of washing hands before eating	193	49	44–54
Importance of washing hands for preventing jaundice	295	75	71–79
Importance of washing hands before preparing food	378	96	94–98
Messages on chlorination			
Chlorinated water is drinkable	107	27	67–76
Chlorination prevents jaundice	264	67	28–37
Chlorinated water is not dangerous	179	46	49–59
Chlorine is available at water points	148	38	57–66
Messages on jaundice			
Jaundice is transmitted by contaminated water	149	38	33–43
Jaundice is dangerous for pregnant women and children	140	36	31–41
List 2–3 jaundice symptoms	239	61	56–66
Jaundice is transmitted by hands contaminated with faeces	215	55	50–60

Hygiene kit distribution and hygiene behaviour

Hygiene kits were received by 390 (99%, 95% CI 98–99) households. All households who received a hygiene kit had the four items present (jerry can, plastic goblets, bucket and soap) and also reported having used them.

Soap and water were observed to be present at handwashing points of 391 (99%, 95% CI 98–100) households; 382 (97%, 95% CI 95–99) respondents reported always washing their hands before eating. Soap from the hygiene kit distribution was also reported to be used for washing clothes in 386 (98%, 95% CI 97–99) households and for bathing in 389 (99%, 95% CI 98–100) households.

Water sources, transport and storage

Water was sourced from private wells in 269 (69%, 95% CI 64–73) households, in-home taps in 141 (36%, 95%

CI 31–41) and from the river in 13 (3%, 95% CI 2–6). In 29 (7%, 95% CI 5–10) households, multiple water sources were used.

Households primarily transported water using 20 litre containers ($n = 389$, 99.2%, 95% CI 98–100), with 3 (0.8%, 95% CI 0–2) using 25 litre containers. Within households the median storage capacity of water containers was 50 (range 2–8,050) litres; the extreme upper value corresponded to a single household with a large storage tank.

Free residual chlorine testing

Water tested for FRC was stored in a ceramic jar by 391 households (99%, 95% CI 98–100), with one household (0.3%, 95% CI 0–2) storing in a jerry can. Water in the tested container had been refilled on the day of interview by 224 (57%, 95% CI 52–62) households, the evening before by 139 (36%, 95% CI 31–40) households and the morning of the previous day by 26 (7%, 95% CI 5–10) households. Three (1%, 95% CI 0–2) households refilled their water at least 2 days before the interview.

Chlorination had been accepted by 381 (97%, 95% CI 95–99) households last time they refilled the tested storage container.

The overall median FRC level measured was 0.1 mg/L (range 0.1–3). Containers that had been empty prior to being refilled and containers that had been refilled within the previous 6 hours had a median FRC value of 0.3 mg/L (range 0.1–3) which is above the safe level of ≥0.2 mg/L (Table 2).

Among all surveyed households, 167 (43%, 95% CI 38–48) had a safe FRC level in their stored drinking water. Among those households whose storage container was empty at time of refill ($n = 159$), 104 (65%, 95% CI 57–73) had a safe FRC level, compared to 20 of 76 (26%, 95% CI 17–38) households with a quarter-filled container. Of households who refilled water within the last 6 hours ($n = 136$), 81 (60%, 95% CI 51–68) had a safe FRC level, compared to 0 of 5 (0%, 95% CI 0–54) households who refilled over 24 hours previously. Of households who collected water from private wells ($n = 269$), 125 (46%, 95% CI 40–53) had safe FRC levels, compared to 40 of 118 (34%, 95% CI 26–43) households who collected from in-home taps (PR 0.8, 95% CI 0.5–1.0) (Table 3).

Table 2 | Median FRC values in household storage containers, overall and by various factors, Am Timan ($n = 392$)

	Median	Range
Overall	0.1	0.1–3
Water level before refill		
Empty	0.3	0.1–3
One-quarter	0.1	0.1–1
Half	0.1	0.1–3
Three-quarters	0.2	0.1–0.3
Time since last filled		
0–6 hrs	0.3	0.1–3
6–18 hrs	0.1	0.1–3
18–24 hrs	0.1	0.1–1
>24 hrs	0.1	0.1–0.1
Most commonly used source		
Private wells	0.1	0.1–2
River	0.1	0.1–0.6
In-home taps	0.1	0.1––3

Stratifying by level of water in the container at refill (empty versus not) indicated that water maintained a safe FRC level for a longer period of time when added to an

Table 3 | Number of households with safe FRC levels (≥0.2 mg/L) in water storage containers, overall and by various factors, Am Timan ($n = 392$)

	Total	n (%)	95% CI[a]	PR[a]	95% CI
Overall	392	167 (43)	38–48		
Water level before refill					
Empty	159	104 (65)	57–73	Ref.	
One-quarter	76	20 (26)	17–38	0.4	0.2–0.6
Half	133	31 (23)	17–32	0.4	0.2–0.5
Three-quarters	24	12 (50)	31–69	0.8	0.4–1.3
Time since last filled					
0–6 hrs	136	81 (60)	51–68	Ref.	
6–18 hrs	194	70 (36)	29–43	0.6	0.4–0.8
18–24 hrs	57	16 (28)	17–42	0.5	0.3–0.8
>24 hrs	5	0 (0)	0–54	NA	NA
Most commonly used source					
Private wells	269	125 (46)	40–53	Ref.	
River	5	2 (40)	7.3–83	0.8	0.1–2.7
In-home taps	118	40 (34)	26–43	0.8	0.5–1.0

[a]95% CI = confidence interval calculated for single proportion from a Pearson chi-squared test; PR = prevalence ratio.

empty container. The median FRC was 0.3 mg/L (range 0.1–2) at 18 hours in empty containers versus 0.1 mg/L (range 0.1–0.3) in partially full containers. For empty water containers refilled between 0 and 6 hours, 77% (95% CI 65–86) had a safe FRC level compared to 41% (95% CI 29–54) of partially full containers ($p = 0.037$). This extended to 18–24 hours since refill where 41% (95% CI 21–63) of empty containers had a safe FRC level compared to 20% (95% CI 9–37) of partially full containers ($p = 0.159$).

Households which had refilled water containers within the last 18 hours compared to over 18 hours (PR 1.8, 95% CI 1.1–3.1), those who sourced water from private wells compared to other sources (PR 1.4, 95% CI 1.0–2.0) and those who poured water into a previously empty container compared to partially full containers (PR 2.4, 95% CI 1.8–3.3), were all more likely to have safe FRC levels (Table 4).

DISCUSSION

Our study results indicate high coverage of hygiene promotion activities and a successful hygiene kit distribution in the community. Hygiene kit items were present in households and almost all respondents indicated that they used soap for washing clothes and bathing in addition to handwashing. While it cannot be ascertained whether personal hygiene at the household level was improved as a result of the interventions, the fact that soap was available and people were able to recall multiple prevention messages without being prompted, does suggest the potential for an improved hygiene environment and hence reduced household transmission. Our finding is supported by a previous study during a cholera outbreak in Haiti suggesting that when a distribution of kits containing hygiene items was coupled with intensive hygiene messaging, it did lead to a notable increase in self-reported use of the items (Gartley *et al.* 2013).

The importance of personal hygiene has been demonstrated in other recent HEV outbreaks where person-to-person transmission was identified as an issue (Howard *et al.* 2010; Teshale *et al.* 2010). One of these studies identified shared handwashing basins as an important risk factor for transmission (Howard *et al.* 2010). In the setting of Am Timan, rather than the use of basins, plastic kettles were used for pouring water during handwashing, thus it may be that while messaging and hygiene item coverage was high, the impact of the intervention could be improved by tailoring messaging to the specific setting. Given the multiple transmission routes of HEV, both of the mentioned studies emphasised the need for household level hygiene promotion to be equally as important as physical interventions. This finding is corroborated by our study as well as the need for a multi-model outreach strategy; and in this setting we found that face-to-face interaction at the household was the most effective method of hygiene promotion.

Our second important finding relates to the challenge of achieving safe FRC levels at the point of consumption. One key factor is the acceptance of chlorination by the population. At the time of the survey, 98% of respondents reportedly accepted chlorination; however, it should be noted that at the beginning of the outbreak the proportion of people refusing chlorination was high (17%). In Am Timan, rather than being linked to taste and odour issues, this high rate of refusal was linked to the religious practice of using only natural water sources for partial ablutions before prayer. Fortunately, this was promptly addressed and resolved through engaging with religious leaders followed by intensive sensitisation of the population. It does highlight, however, the need for in-depth understanding of the context before implementing physical interventions such as chlorination, particularly in a population which is unfamiliar with the use of water treatment products.

On the technical aspects, evidence confirms that current guideline FRC values (0.2–0.5 mg/L) are sufficient to inactivate HEV (Girones *et al.* 2014; Guerrero-Latorre *et al.* 2016). Our unpublished bucket chlorination monitoring data from the Am Timan outbreak indicated that FRC levels of $\geq$0.5 mg/L after 30 minutes' contact time were consistently delivered at the point of collection. However, at the point of consumption without any time or storage factors taken into consideration, we measured a safe FRC level in only 43% of households. We were unable to identify a particular water source type as being the reason for this low coverage. We did, however, find two other potential reasons: the mixing of old and freshly chlorinated water in household storage containers; and the time since water in storage containers was chlorinated and refilled.

Our study found that almost all respondents used plastic jerry cans for water transport, but then transferred it into larger (60 L) ceramic storage vessels in their homes. Households who reported putting freshly collected water into empty storage vessels compared to those who did not, had more than twice the chance of having a safe FRC level. Storing water in large open-mouthed storage containers has been associated with HEV infection in a previous outbreak (Guerrero-Latorre *et al.* 2011). Studies from non-emergency settings have shown recontamination of previously safe water during storage (Clasen & Bastable 2003; Wright *et al.* 2004). Similar findings in refugee camp settings demonstrated recontamination after collection (Steele *et al.* 2008), and a link to continued spread of diarrhoeal disease (Swerdlow *et al.* 1997; Roberts *et al.* 2001; Shultz *et al.* 2009; Mahamud *et al.* 2012). This is expected given that mixing and manipulation of water will clearly affect FRC; however, it serves as an important reminder for responders to understand this dynamic and educate people on safe water handling practice.

With regard to time since chlorination, households with recently collected water (<6 hours) had a significantly higher chance of having a safe FRC level at the time of our testing. Furthermore, through our analysis we were able to establish a cut-off point of 18 hours whereby there was a statistically higher chance of measuring a safe FRC level in stored water.

Recent FRC decay studies in refugee camps in South Sudan attempted to measure safe levels at the household level up to 24 hours after distribution (Ali *et al.* 2015). As in our study, it was shown not to be possible, resulting in recommendations to review disinfection practice and guideline standards. Furthermore, additional empirical studies in camps in different climates has shown the rate of FRC decay in water to be strongly related to the initial chlorine dose as well as conductivity, exposure to sunlight and temperatures above 30 °C (Ali *et al.* 2016, submitted). In Am Timan, the storage containers were, anecdotally, open-mouthed and uncovered and ad-hoc water point quality data recorded a temperature range of 27 °C–35 °C, confirming the need to review our standard operating practices.

A recent wide ranging review of knowledge on chlorination of drinking water in emergencies suggests that response agencies should try to meet a minimum standard of 0.2 mg/L FRC in the recipient's cup at the moment of consumption (Branz *et al.* 2017). In future outbreaks, we will then need to revise our criteria for deciding the initial chorine dose required at the point of collection. Although one study has shown that users accept chlorine levels up to 2.0 mg/L (Lantagne 2008), this is highly population dependent and simply increasing the FRC concentration may be inappropriate for taste, odour and, as we have seen, religious practice reasons. We will need to take this into account as well as adapting our messaging around the need to regularly replenish water, cover water containers and to store these out of direct sunlight.

In Am Timan, water use and practice is diverse, with a majority of people using private wells where payment for water is common, while others access piped networks and river water. This survey was conducted during the dry season and river water was mostly inaccessible, however this was anecdotally observed to be an important source of water several months earlier. This is very different to camp settings where agencies can control where and when water is collected. We found that those taking water from 'private wells' were more likely to have a safe FRC level compared to other sources; however, we were unable to pinpoint exactly which source type was not being effectively chlorinated. Additionally, it is well documented that FRC levels decrease in piped distribution systems, and in Am Timan chlorination of the town water supply was intermittently interrupted due to technical issues with the chlorine

Table 4 | Factors associated with having safe FRC level (≥0.2 mg/L) in water storage containers, Am Timan (*n* = 392), using univariate poisson regression

Factor	Category	Safe FRC level *n* (%)	PR	95% CI	*p* value
Time since last filled	<18 hrs; > =18 hrs	151 (46); 16 (26)	1.8; Ref.	1.1–3.1	0.029
Most commonly used water source	Private wells; Any other source	125 (47); 42 (34)	1.4; Ref.	1.0–2.0	0.084
Water level before refill	Empty; Not empty	104 (65); 63 (27)	2.4; Ref	1.8–3.3	<0.001

dosing system. Thus, in resource limited settings it may be the case that interventions such as controlled bucket chlorination or further treatment at household level are potentially more effective methods of delivering safe drinking water, especially during outbreaks. Understanding these mixed water sources which are context- and season-dependent has important implications for ensuring efficient water treatment.

In the Am Timan outbreak, HEV cases remained fairly stable for two months after our survey before declining. Considering the long incubation period (mean 40 days) of HEV infection it is possible that the interventions did indeed mitigate against a large-scale propagation of the outbreak; however, they may also have had no effect. One modelling study showed that the timing of interventions during a HEV outbreak is very important and that in a previous outbreak timely action probably led to a 4.9–6.7% reduction in total cases (Mercer & Siddiqui 2016). Our survey did not intend to directly measure health impact as we fully appreciate this is methodologically challenging in outbreaks and emergencies, as highlighted in recent systematic reviews (Taylor *et al.* 2015; Yates *et al.* 2017). This is an area where research methodologies need to be adapted and tested in future outbreaks.

LIMITATIONS

Our study suffered from several limitations. First, social desirability bias may have led to an overestimation of self-reported measures, as participants may have felt that they would receive further benefits; surveyors made every effort to explain this was not the case. There may have also been a further bias in our survey as we asked participants to recall hygiene messages before asking about their practices. Second, it was not possible to distinguish whether river water was sourced from the MSF jetted well, which was chlorinated, or the river itself; thus the collected data does not necessarily reflect that particular intervention. Third, the pool-testers used for FRC measurement were graduated with readings at 0.1, 0.3 and 0.6 mg/L and above, thus it may be that the FRC level recorded was inaccurately above or below the safe threshold. Furthermore, testing FRC in the water storage container indicated by the respondent as being most frequently used for drinking may have led to an overestimation of FRC levels as a whole.

Our intervention did not include a sanitation component, as this was deemed to be a lower priority at the time given the open setting and limited resources; however, this may have been an important factor given the faecal/oral route of HEV transmission.

The lack of a baseline survey to assess the initial status of hygiene, health behaviours and water handling practices, means that it is impossible to judge whether the interventions led to an improvement in these areas. Finally, it was not possible to conduct a multivariable analysis, controlling for confounders and effect modifiers, due to sample size restrictions.

CONCLUSIONS

While other studies (Wang *et al.* 2016; Mudau *et al.* 2017) have reported the importance and challenges of ensuring safe FRC levels in drinking water during outbreaks, this is the first report describing implementation of controlled chlorination at the point of collection and the subsequent FRC levels found at the point of use. Our study findings indicate that, although challenging and resource intensive, provision of chlorinated water and hygiene promotion interventions are feasible and accepted by the population in an open setting, during an HEV outbreak.

Findings suggest that while high coverage of messaging is possible, it is important to tailor messages to the specific setting of the outbreak, requiring formative research through engagement with community leaders from the outset.

We would particularly like to highlight the need for agencies, implementing water treatment interventions, to take account of the documented factors which affect FRC decay: the initial chlorine dose, ambient and water temperature, water handling and storage practices and time since water collection (Ali *et al.* 2016). This will mean that response agencies should ideally prioritise access to sufficient treated water to enable daily collections during an outbreak. Furthermore, in light of the review on chlorination of drinking water in emergencies (Branz *et al.* 2017), it is critical that other experiences similar to ours be documented and made available for review, to contribute to the evidence base on which to inform effective implementation of chlorination programmes.

Further studies evaluating the effectiveness of bucket chlorination, change in water handling and hygiene practices pre- and post-interventions in open settings should be considered and must include more rigorous and accurate survey and testing methods. More importantly, study protocols employing household cohorts should be developed, as these could prospectively investigate the effectiveness of water treatment interventions at interrupting transmission of HEV and other waterborne disease outbreaks.

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