Faecal contamination of drinking water during collection and household storage: the need to extend protection to the point of use

Thomas F. Clasen and Andrew Bastable

ABSTRACT

Paired water samples were collected and analysed for thermotolerant coliforms (TTC) from 20 sources (17 developed or rehabilitated by Oxfam and 3 others) and from the stored household water supplies of 100 households (5 from each source) in 13 towns and villages in the Kailahun District of Sierra Leone. In addition, the female head of the 85 households drawing water from Oxfam improved sources was interviewed and information recorded on demographics, hygiene instruction and practices, sanitation facilities and water collection and storage practices. At the non-improved sources, the arithmetic mean TTC load was 407/100 ml at the point of distribution, rising to a mean count of 882/100 ml at the household level. Water from the improved sources met WHO guidelines, with no faecal contamination. At the household level, however, even this safe water was subject to frequent and extensive faecal contamination; 92.9% of stored household samples contained some level of TTC, 76.5% contained more than the 10 TTC per 100 ml threshold set by the Sphere Project for emergency conditions. The arithmetic mean TTC count for all samples from the sampled households was 244 TTC per 100 ml (geometric mean was 77). These results are consistent with other studies that demonstrate substantial levels of faecal contamination of even safe water during collection, storage and access in the home. They point to the need to extend drinking water quality beyond the point of distribution to the point of consumption. The options for such extended protection, including improved collection and storage methods and household-based water treatment, are discussed.

Key words | collection, contamination, household, point-of-use, storage, water

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BACKGROUND

Contaminated drinking water, along with inadequate supplies of water for personal hygiene and poor sanitation, are the main contributors to an estimated 4 billion cases of diarrhoea each year causing 2.2 million deaths, mostly among children under the age of five (WHO 2000*a*). Under guidelines established by the World Health Organization (WHO), water intended for human consumption should contain no microbiological agents that are pathogenic to humans (WHO 1993). The minimum standards for emergency disaster response developed by the Sphere Project allow up to 10 faecal coliforms (FC) per 100 ml for non-disinfected supplies, but are currently under revision (Sphere Project 2000). Notably, both the WHO guidelines and the Sphere Project minimum standards for untreated sources are expressed in terms of water quality at the point of delivery, thus imposing no obligation to ensure quality through to the point of consumption.

The risk of microbiological contamination of drinking water during collection and storage in the home has long been recognized (van Zilj 1966; VanDerslice & Briscoe 1995). Field investigations have identified certain practices and vessel characteristics that are associated with the

contamination of household water or the disease resulting therefrom, such as using large-mouth vessels to collect and store water (Mintz *et al.* 1995), transferring water from collection vessels to storage vessels (Lindskog & Lindskog 1987), and accessing water by dipping hand-held utensils rather than via a tap or by pouring (Hammad & Dirar 1982; Swerdlow *et al.* 1997). After contamination occurs, the design of the vessel (Patel & Isaacson 1989) and the time period before consumption (Roberts *et al.* 2001) also influence the survival of the bacteria.

In the last decade, most of the work in this area has focused on interventions that can reduce contamination of household water and produce a measurable health impact. One intervention developed by the Centres for Disease Control and Prevention (CDC) and the Pan American Health Organization (PAHO) combines: (i) point-of-use water disinfection using sodium chloride manufactured locally through electrolysis of brine; (ii) a specially-designed water storage vessel with a narrow mouth to prevent ingress of hands and a spigot for drawing water for consumption; and (iii) community hygiene education and training and follow-up in the use of the disinfectant and vessel (CDC 2001). Trials involving the intervention have demonstrated reductions in the incidence of diarrhoea of 44% in Bolivia (Quick 2002) and 62% in Uzbekistan (Semenza 1998). Even without chlorination, however, an improved collection and storage vessel was associated with a 69% reduction in geometric mean FC count and a 31% reduction in diarrhoea in children under five ($P = 0.06$) (Roberts *et al.* 2001).

Oxfam GB has been continuously engaged in water, sanitation and hygiene promotion in Sierra Leone since 1998, initially within camps providing refuge to those displaced by the 10-year war, and most recently under UNHCR contracts to develop and rehabilitate wells and other water sources for returning refugees in the Kailahun and Koindu Districts, the areas most affected by the war. Aware of the growing evidence of faecal contamination of water in the home, it undertook this study to evaluate the extent to which untreated water from sources it develops is subject to post-delivery contamination, and if so, to identify risk factors and possible interventions.

METHODS AND MATERIALS

Thirteen towns and villages in the Kailahun District of Sierra Leone were selected to participate in a cross-sectional study of the faecal contamination of drinking water collected and stored in households. Located on the border with Guinea and Liberia, the area had been a stronghold of the Revolutionary United Force and thus had been almost entirely vacated by the resident population. Most of the refugees had returned only in the previous several months, and many new returnees were arriving daily. Because most of their houses had been destroyed or rendered uninhabitable, many of the returnees were sharing houses or were living in traditional rural structures. The selected towns and villages included most of the sites in which Oxfam had developed or rehabilitated at least one water source. Three existing water sources in the same region, which had not yet been rehabilitated by Oxfam, were also sampled.

During June and July 2002 (the beginning of the rainy season), paired water samples were collected from each of the 20 designated sources and from 5 randomly selected households using each such source. Samples were collected in sterile 100 ml Whirl-packs (Nasco International, Inc., Ft Atkinson, WI, USA). Source water was sampled without first flaming the outlet so that the sample would reflect normal collection procedure and any contamination associated therewith. Household samples were collected from the storage vessel then being used for drinking water. The female head of household was asked to provide the sample by demonstrating how she would obtain drinking water for a child. The sample was then taken from the cup or other utensil from which the water would have been consumed. Household samples were coded and matched with the source from which they were drawn.

All samples were analysed within 4 h using the membrane filter technique (*Standard Methods* 2000). 50 ml samples were passed through a 0.45 micron membrane filter (Millipore Corporation, Bedford, Massachusetts, USA) and incubated on membrane lauryl sulphate media (Oxoid Limited, Basingstoke, Hampshire, England) at $44°C \pm 0.5°C$ for 18 h in an Oxfam Delagua portable incubator (Robens Institute, University of Surrey, Guildford, Surrey, UK). Each incubation cycle included a negative

control consisting of water passed through a portable water microfilter with a 0.3 micron membrane (Katadyn Products, AG, Zurich, Switzerland). The number of yellow colonies were counted and recorded as individual thermo-tolerant coliforms. When a volume of 50 ml produced a number of colony-forming units (CFU) that were too numerous to count (TNTC), the count was recorded as TNTC and assigned a value for purposes of statistical analysis of 1000 TTC colonies per 100 ml. Representative TTC colonies were identified as *Escherichia coli* by spot indole reagent (Remel Inc., Norcross, Georgia, USA).

To obtain more detailed information on factors that may be associated with post-delivery contamination of safe water, the 85 households drawing their water from Oxfam sources were interviewed using a standard questionnaire. The female head of household was asked to respond to questions on a variety of issues, including educational and demographic data, hygiene instruction during the previous 6 months, any experience of diarrhoea (defined as three or more loose stools in 24 h) within the previous 48 h by any member of the household sharing the same drinking water container, hand washing practices, sanitation facilities, and water collection and storage practices. Data were recorded and analysed on EPI-INFO 2000, with additional statistical analysis performed on STATA 7.

RESULTS

Table 1 sets forth the type and TTC count for each source. Fifteen (88.2.1%) of the Oxfam-improved sources were completely free of faecal contamination; the samples taken from the other two wells each had 2 TTC/100 ml, a level that is compatible with contamination of the tap due to non-flaming. Of the sources sampled that had not yet been rehabilitated by Oxfam, the mean TTC load was 407. As would be expected, the difference in mean TTC counts at the Oxfam and non-Oxfam sources is highly significant ($P<0.0001$). Apart from the non-Oxfam sources, where the previously improved spring was of higher micro-biological quality than the traditional wells, there were no statistically significant differences in TTC level by source type.

Table 1 │ Thermotolerant coliform count at source and household by source type

Source type	N	Mean TTC count at source	Mean TCC count at household
Oxfam sources:	17	0.23	244
New hand-dug well	3	0	192
New borehole	9	0.44	249
Rehabilitated well	5	0	264
Non-Oxfam sources:	3	407	882
Traditional hand-dug well	2	520	938
Previously improved spring	1	182	770

At the non-improved sources, the mean TTC load was 407/100 ml at the point of distribution, rising to a mean count of 882/100 ml at the household level. Water from the improved sources, on the other hand, met WHO guidelines, with no faecal contamination other than mini-mal levels probably associated with human touching of the pump outlet.

During the same period, drinking water samples were taken and analysed from the stored water at a total of 100 households, 5 from each of the sampled sources (Table 1). The arithmetic mean TTC count from households drawing water from Oxfam-improved sources was 244 (95% CI: 170, 316) and the geometric mean was 77 (95% CI: 50, 117). This level is comparable to the mean TTC counts in household stored water of 250/100 ml (Lindskog & Lindskog 1987) and 218/100 ml (Hammad & Dirar 1982) and is consistent with other research on the extent of faecal contamination of drinking water during collection and storage (Hammad & Dirar 1982; Lindskog & Lindskog, 1987; VanDerslice & Briscoe 1995; Roberts *et al.* 2001). Among households drawing water from non-Oxfam improved sources, the arithmetic mean TTC count was 882. The difference in means at the household level between those using Oxfam improved sources and those using previously existing sources was statistically significant at the 95% confidence level ($P = 0.0024$).
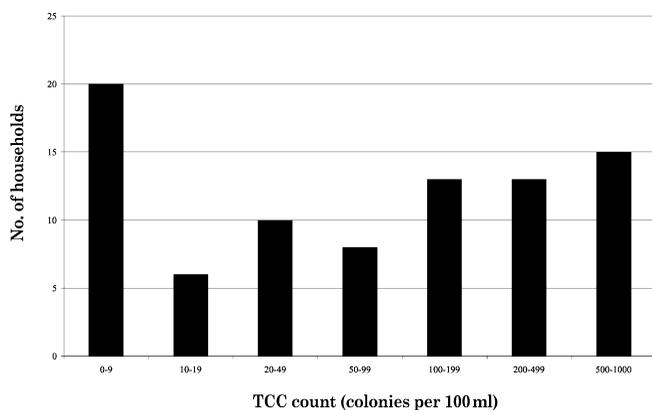
Figure 1 │ Frequencies of households by TTC level.

TTC were present in 100% of the 15 samples from households using non-Oxfam improved sources. Unfortunately, it was almost as common in the stored water of households using improved Oxfam sources. TTC were present in the drinking water of 79 (92.9%) of these 85 Oxfam-supplied households tested. 76.5%, 69.4%, 57.6% and 48.2% of these households exceeded 10, 20, 50 and 100 TTC per 100 ml, respectively (see Figure 1). Eleven (12.9%) of the household samples were TNTC and were allocated a value of 1000 TTC colonies per 100 ml.

The age, level of education and previous hygiene instruction of the female head of household were not predictive of the extent of the TTC load of water stored in the home. Neither was the number of rooms in the household, the number of persons accessing their drinking water from the same storage vessel or whether persons sharing the drinking vessel was currently reported to have diarrhoea. Similarly, hand washing practices and sanitation facilities were not associated with statistically meaningful differences in TTC loads of stored drinking water. Neither hand washing agents used by the female head of household, nor the presence of soap in the home at the time of the interview were determinative of TTC loads in stored drinking water.

Data on water storage and access practices were also analysed. Like other studies cited above, lower mean TTC counts were associated with the practice of maintaining drinking water in the same vessel in which it was collected rather than transferring it to another vessel, though the

difference in means in this study (184 *vs* 292, respectively) did not reach customary levels of statistical significance. Most households access their drinking water by dipping a cup or other utensil into the storage vessel (78.8%), rather than pouring from the vessel (8.2%) or drawing water from a tap or spigot (12.9%). The data did indicate that using a tap or spigot to access water is protective of stored water quality (arithmetic mean TTC count = 97) compared with water in which access was obtained by dipping (252) or pouring (391) ($P = 0.05$).

DISCUSSION

Each year, governmental agencies, NGOs and others develop and improve thousands of wells, boreholes, springs and other sources of supply to provide desperate villages and other localities with communal sources of safe drinking water. The goals under the Millennium Declaration, as confirmed by the Johannesburg Summit, to halve the number of people without access to safe water by 2015, are expected to accelerate the commitment of resources devoted to this critical area. Guidelines for engineers stress the need to 'protect' these untreated sources from subsequent contamination with sanitary seals, caps, aprons and spillways around wells and boreholes, and carefully constructed spring boxes, diversion ditches and fences around springs (Cairncross & Feachem, 1993; Davis, 2002). Although these efforts may increase the quantity of water available for hygiene and thereby have a positive impact on human health, data from Sierra Leone and other studies demonstrate that safe water at the source may nevertheless contain high levels of microbial pathogens at the time it is consumed. While there is some debate over the extent to which interventions to improve drinking water quality alone translate into reductions in water-related disease (Esrey *et al.* 1985, 1991), the failure to ensure water quality from delivery to use represents a serious shortcoming in existing efforts to maximize health through drinking water improvements.

Unlike treated water which must normally contain prescribed levels of residual disinfectant to prevent recontamination, untreated water drawn from communal

sources is not subject to post-delivery protective measures under existing guidelines, standards or international commitments. As noted above, both WHO guidelines and Sphere Project minimum standards for untreated water are expressed in terms of water quality at the point of delivery and collection, not at the point of consumption. The Global Water Supply and Sanitation Assessment, which cites the drinking water targets of the Millennium Declaration, does not address recontamination, distinguishing only between water supplies that are 'improved' (household connection, public standpipe, borehole, protected well or spring and collected rainwater) or 'not-improved' (unprotected well or spring or vendor/tanker provided water) (WHO 2000*b*). Perhaps as a result, those engaged in the development of communal water sources may not be focusing on the need to ensure that water remains pathogen free following distribution at the pump or tap. It must be understood, however, that water is not an *agent* of disease, but a *medium* through which disease may be spread. Because water collected at such sources contains no residual disinfectant, it is immediately vulnerable to faecal contamination, creating an insidious pathway for human disease and effectively negating the efforts to ensure the integrity of the source water. In order to ensure maximum health gains, these guidelines and international commitments should be extended to ensure that drinking water is safe at the point of consumption and not just the point of delivery.

Some have argued that the health impact of these household pathogens, believed to be recycling in the domestic domain, is slight compared to those that may enter the community and circulate quickly in a water supply (Feachem *et al.* 1978; VanDerslice 1993). This is obviously not the case in emergency and post-emergency contexts such as here, where dozens of unrelated people coming from various locations may share the same water storage vessel. Moreover, recent studies that measure health impact have demonstrated substantial reductions in diarrhoeal disease, including cholera and dysentery, from the use of safer water collection and storage vessels (and household disinfection in the case of contaminated supplies), combined with appropriate hygiene instruction (Mintz *et al.* 1995; Roberts *et al.* 2001). Infant formula

made from water contaminated in the home may be a particular threat (VanDerslice 1994; Dune *et al.* 2001). The immuno-compromised are particularly at risk and under-fives, who experience the highest rates of mortality from diarrhoeal disease, are vulnerable to smaller doses of pathogens than may affect other family members (Mintz *et al.* 2001).

Apart from residual disinfection of these communal sources, there are two fundamental approaches to ensuring microbiological quality through to the point of consumption. The first is to 'protect' microbiologically safe water through improved collection, storage and access. While this includes behavioural aspects, including hygiene and sanitation, an improved vessel can significantly reduce the extent of post-delivery faecal recontamination. Key features of the vessel include: (i) an opening that is large enough to facilitate filling but too small to allow hands to enter; (ii) a size, shape, weight and durability that renders it suitable to be taken to and filled at the pump to eliminate transfers to another vessel; and (iii) a spigot or tap for access without inserting cups or other utensils (Mintz *et al.* 1995). Plastic blow-moulding, the method of producing such vessels, and injection moulding for the spouts, would be available locally in all but the least developed countries. Finally, creative engineers may be able to design a universal cap for locally available jerry cans that incorporates the spigot, and if necessary a one-way air make-up valve. If successful, this cap could then be produced *en masse* abroad, and shipped economically to the country to be matched up with existing supplies of jerry cans, some of which may already be in the target population's possession.

The use of improved vessels alone has been associated with decreases in microbiological contamination and reductions in diarrhoeal disease (Deb *et al.* 1986; Roberts *et al.* 2001). The fact that they are also suitable for home-based chlorination would offer additional flexibility in dealing with particular situations. At the early stages of a water source development programme, the vessel could be distributed with an inexpensive chemical disinfectant or combined coagulant/disinfectant in order to bridge the period prior to the availability of safe water. In small or remote locations, or where safe water sources are not

feasible, the vessel and disinfectant could be a cost-effective permanent intervention alternative, as demonstrated in a number of cases (Mintz *et al.* 2001). The vessel and disinfectant would also be an important tool in controlling outbreaks of cholera, dysentery or other life-threatening diarrhoeal diseases. Finally, the combination of vessel and disinfectant could be an important intervention in protecting populations that would be particularly vulnerable to the level of contamination that occurs in stored water, such as the immuno-compromised or infants of mothers with HIV/AIDS who must choose between the risk of infecting their newborns with the virus by nursing them and the risk of diarrhoeal disease from infant formula made with contaminated water (Dune *et al.* 2001).

The second, and perhaps most efficient means of ensuring that water is safe at the point of consumption is by focusing intervention efforts at the point of use. This is the focus of a comprehensive report recently published by the WHO (Sobsey 2002). Promotion of such alternatives reflects the organization's acknowledgement that piped-in water supplies will continue to be unavailable to hundreds of millions of people. It also reflects the WHO's acknowledgement of the effectiveness of certain point-of-use systems, and the potential they have for accelerating the benefits of healthy drinking water to the 1.1 billion who will wait decades for the infrastructure to reach them. Among the various approaches to household-based water treatment are heat and UV radiation, sedimentation, filtration and chemical treatment (coagulation, flocculation, precipitation, adsorption and disinfection). Certain of these approaches, such as the CDC's 'Safe Water System' of in-home chlorination combined with safe storage and hygiene instruction, and the SODIS system of solar disinfection in clear bottles (UV and heat treatment), have already undergone extensive evaluation (Conroy *et al.* 1999; CDC, 2001). Others, such as ceramic microfiltration and in-home flocculation/disinfection, have been shown to be effective in the laboratory and are currently undergoing field trials.

These treatment options are primarily focused on unimproved water sources. Thus, while they may be effective in dealing with the post-delivery contamination that is being experienced in Sierra Leone, they are perhaps excessive in this context where the supply is of high microbiological quality. However, given the time and costs of developing or rehabilitating wells and other sources of supply (including manpower, supplies and equipment, logistics and support) and maintaining them in operating condition (manpower and parts), it will be cost-effective in particular circumstances to rely on existing sources of supply (traditional wells and unprotected sources) and simply implement some of these other options to ensure microbiological quality.

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