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Chlorination and safe storage of household drinking water in developing countries to reduce waterborne disease

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Abstract Simple, effective and affordable methods are needed to treat and safely store non-piped, gathered household water. This study evaluated point-of-use chlorination and storage in special plastic containers of gathered household water for improving microbial quality and reducing diarrhoeal illness of consumers living under conditions of poor sanitation and hygiene. Community families were recruited and randomly divided into intervention (household water chlorination and storage in a special container) and control (no intervention) households. Microbes in stored household water were extensively inactivated by 1–5-mg/L doses of hypochlorite. *Escherichia coli* levels in stored household waters were <1/100 mL in most intervention households but readily detectable at high levels in control households. Stored water of intervention households was also lower in *Clostridium perfringens* and heterotrophic plate count bacteria than in control households. The intervention reduced household diarrhoeal illness. In Bolivia, monthly episodes of household diarrhoeal illness were 1.25 and 2.2 in intervention and control families, respectively (P = <0.002) indicating that 43% of community diarrhoea was preventable by using the intervention. In Bangladesh, mean episodes of child diarrhoea/1,000 d were 19.6 and 24.8 in intervention and control groups respectively (P = <0.03) indicating that about 24% of observed diarrhoea was preventable by using the intervention. Chlorine disinfection and storage in an appropriate container significantly improved the microbiological quality of non-piped household drinking water and reduced community diarrhoeal disease. Widespread use of this simple treatment and storage system for non-piped domestic water has the potential to dramatically reduce the global burden of waterborne diarrhoeal disease.

Keywords Chlorination; diarrhoea; household; non-piped water; treatment

Introduction

Much of the world's population lacks access to adequate and safe water supplies with waterborne disease and death continuing to be a worldwide burden in both developed and developing countries. Waterborne infectious diseases are caused by a variety of microbial agents (pathogens) that contaminate drinking water supplies in developed and developing countries. In the developing world, children and adults suffer repeated episodes of infectious diarrhoeal disease annually and water is a major source of exposure to diarrhoeal pathogens. It is estimated that perhaps 15–20% of community diarrhoeal disease in developing countries is attributable to unsafe drinking water with recent studies indicating even higher percentages of waterborne diarrhoeal disease (Quick *et al.*, 1999). Even in developed countries, as much as 15–30% of community gastroenteritis (diarrhoeal illness) has been attributed to municipal drinking water despite state-of-the-technology water treatment, no measurable levels of pathogens in the water and no other evidence of unacceptable levels of microbial contamination (Payment *et al.*, 1991, 1999).

Much of the global population now consumes untreated, non-piped drinking water usually consisting of small volumes (<40 L/d) collected and stored in the home by the users. Typically, people collect water from any available source and store it in a vessel or container in the home for domestic and potable use, often without treatment and protection from further contamination. In many cases, this water is obtained from faecally contaminated sources, collected in open or otherwise unprotected containers and then stored in the same

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containers under unsanitary conditions in the home. Such collected household water is often heavily contaminated with faecal microbes and poses high risks of exposure to waterborne pathogens. In addition, many urban and rural piped water supplies are also faecally contaminated due to deficiencies such as poor source water quality, inadequate water treatment and distribution system vulnerability to infiltration of faecally contaminated, non-potable water, including sewage. Even piped water supplies of adequate microbial quality can pose infectious disease risks if they become contaminated due to unsanitary collection and storage conditions and practices within households. Considering all of these vulnerable water supplies and sources, it is likely that most of the water collected and stored in households for drinking and other domestic use in developing countries is or becomes faecally contaminated and poses infectious disease risks.

There is now compelling evidence to document that improving microbiological water quality can appreciably reduce waterborne infectious disease risks, even in the absence of improved or adequate sanitation (excreta disposal). This is an important finding because, until recently, it was mistakenly believed that improved sanitation was essential for reducing diarrhoeal and other diseases and that improving only water quality would have little effect on the risks of enteric diseases when sanitation conditions were inadequate. While improvements in both water quality and sanitation will have the greatest effect in reducing diarrhoeal and other infectious diseases, it is now clear that improvement in water quality alone has a beneficial effect on health.

Several simple, accessible, appropriate and affordable systems to improve the microbiological quality of collected household water by treatment and to protect it by storage in an appropriate container have been identified, evaluated and are now being implemented worldwide. One is manual chlorination and storage in a narrow-mouth plastic vessel designed to minimize further contamination during storage and use (Mintz *et al.*, 1995, 2001; Reiff *et al.*, 1995; Quick *et al.*, 1996). Another system is solar disinfection in which water is put in clear, plastic, disposable beverage bottles and exposed to sunlight for several hours to disinfect it prior to use (Conroy *et al.*, 1996, 1999). Both systems employ inexpensive water storage containers, are simple to use, are affordable and are generally acceptable to users, especially if supported by an educational and motivational program to achieve implementation and maintain effective and sustained use.

The chlorination-safe storage vessel system uses a concentrated free chlorine solution. This is either produced in the community by electrolysis of salt (NaCl) with a simple, low cost electrolytic cell or purchased at low cost from outside (typically commercial) sources. A small volume of the concentrated chlorine solution is added to water that has been placed in a specially designed plastic vessel (typically 12–25 L capacity) having a handle, a medium sized opening for filling and cleaning and preferably a valved spigot for dispensing the disinfected water. Using the container cap as a measuring device, the concentrated free chlorine solution is added to achieve a dose of up to 5 mg/L and the water is stored for several tens of minutes or longer in order for the chlorine to inactivate microbes. This report presents the results of two separate studies on the efficacy of chlorination and storage in an improved vessel to reduce microbial contamination of collected, stored household water and to reduce enteric disease in developing countries as well as other settings where water is collected and stored.

Methods and materials

Study sites, populations, water supplies and sanitation

One study site consisted of two peri-urban settlements near a city of 70,000 people in subtropical Bolivia where shallow groundwater was collected for use by households. The other study was in an informal urban settlement in Dhaka City, Bangladesh, where households collected water primarily from clandestine connections to the municipal water supply which provided water of variable quality and only for a few hours per day. Both study sites had populations of low socioeconomic status and poor sanitation conditions (no sewerage systems and only some latrines). In both studies, families were recruited and randomly assigned to control and intervention groups with about 140 households in the Bolivian study and about 275 households in the Bangladesh study. In both studies, control households used their usual source of water and storage container.

Chlorine and storage vessel interventions

Intervention households were given a plastic water storage container to which chlorine would be added for disinfection of the collected water. The storage container in Bolivia was 20 L capacity with a medium size opening for filling and cleaning, a valved spigot for dispensing water, a handle and a label with pictorial and written instructions for its use with the chlorination intervention. In Bangladesh the storage container was 12 L capacity, had a narrow opening for filling and dispensing water and a handle. In both studies intervention households were given bottles of free chlorine solution (0.25–0.3% free chlorine) weekly. Using the cap as a measuring device, the intervention households were instructed to add sufficient stock chlorine solution to the water container to achieve a dose of about 1.25 mg/L (Bangladesh) or 5 mg/l (Bolivia) free chlorine. In Bolivia, free chlorine was generated by electrolysis of NaCl solution using a MIOX unit (MIOX, Inc., Albuquerque, NM, USA) located in the community and operated by a trained, local worker. In Bangladesh, concentrated free chlorine solutions were prepared by diluting household bleach. Chlorine residuals were measured by the *N,N*-diethyl-*p*-phenelyenediamine colorimetric method. In both studies intervention households were given basic instruction on the use of the intervention. In Bolivia intervention and control households additionally received health education in hygiene and sanitation measures to prevent diarrhoeal disease.

Microbiological analyses

Water samples from intervention and control households in Bangladesh were analysed for faecal coliforms and *Escherichia coli* by MPN using a defined substrate medium in Quantitrays according to manufacturer's instructions (Colilert, IDEXX Laboratories, Westbrook, ME). In Bolivia, water samples were analysed for (a) *E. coli* by membrane filtration on mTEC medium with incubation at 44.5°C for 18–24 h followed by the urease test, (b) *Clostridium perfringens* by membrane filtration on mCp agar at 42°C for 18–24 h followed by exposure of colonies to ammonium hydroxide fumes and (c) heterotrophic plate count (HPC) bacteria by spread plating on plate count agar and incubating at room temperature for 18–24 h. In both studies baseline water samples were analysed before the intervention and they were analysed at regular intervals in control and intervention households during the intervention.

Diarrhoea surveillance

Study households were visited weekly by trained health workers who obtained information about household cases of diarrhoea (defined as ≥3 loose stools within a 24 h period) with onset within the preceding week.

Data analysis

Data on microbiological quality of water were analysed for significant differences by either univariate or multivariate methods including parametric tests (T-test and ANOVAs) or non-parametric tests (Kruskal-Wallis). Data for diarrhoeal illness in intervention and control households and in relation to risk factors were analysed by univariate and multivariate methods including generalized estimating equations, logistic regression and χ^2 tests for significance. Analyses were done with Epi Info Version 6.02 (USD, Inc., Stone Mountain, GA.) and SAS software (SAS Institute, Cary, NC).

Results

Quality of source, stored and treated waters

In Bangladesh baseline studies revealed that the majority (87%) of source water samples were contaminated with faecal coliforms and *E. coli* (geometric mean concentrations of 138 and 29.1 CFU/100 mL respectively). Stored household waters had even higher concentrations of these bacteria with geometric mean concentrations of 280 and 38.6 faecal coliforms and *E. coli*, respectively. During the intervention study, which lasted eight months, the presence of measurable free chlorine in storage vessels in intervention and control households averaged 89% and 21% respectively. Control storage containers sometimes contained measurable free chlorine because the municipal water supply from which the community obtained water was intermittently chlorinated. If anything, the presence of free chlorine in control households should improve the microbiological quality of household water and thereby minimise the beneficial effect of the chlorine intervention in the intervention households. During the 8-month intervention period, the percentage of stored household water samples that were positive for *E. coli* and the geometric mean *E. coli* concentrations in water were significantly lower ($P < 0.01$) in intervention households than in control households (Table 1). These results indicated significant improvement in the microbiological quality of stored water by household chlorination even when the water used by control households sometimes contained measurable free chlorine residuals.

In Bolivia baseline studies revealed that the majority (95%) of household water samples were contaminated with *E. coli*, with median concentrations of 9,200 and 80,000 CFU/100 mL in intervention and control households respectively. These *E. coli* concentrations were not significantly different ($P = 0.3$).

No residual chlorine was detected in any stored household water samples during the baseline survey. During the intervention study, which lasted six months, the presence of measurable free chlorine in storage vessels in intervention and control households averaged 77% and 3% respectively. The occasional presence of free chlorine residual in storage containers of control households was perhaps due to uncontrollable access to chlorine from the central generation facility or occasional sharing by intervention households. During the 6-month intervention period the percentages of stored household water samples positive for *E. coli*, *C. perfringens* and HPC bacteria, as well as the median concentrations of these bacteria in water, were significantly lower ($P < 0.0001$) in intervention households than in

Table 1 *E. coli* positivity and levels in stored water of intervention and control households in Bangladesh

Household	% samples *E. coli* positive	Geometric mean *E. coli*/100 mL
Intervention	12.9	0.7
Control	55.2	4.1

Table 2 Samples negative and median levels of bacteria in stored water of intervention and control households in Bolivia

Household	*E. coli*		*C. perfringens*		HPC bacteria	
	% positive	/100 mL	% positive	/100 mL	% positive	/100 mL
Intervention	33.7	0	37.2	0	58.4	3.5×10^3
Control	93.8	8,300	92.9	72	97.5	2.16×10^6

control households (Table 2). As observed in Bangladesh, these results in Bolivia indicated significant improvement in the microbiological quality of stored water by household chlorination.

Health impact of the water hygiene intervention

In both Bangladesh and Bolivia the health impact of the chlorination and special vessel intervention for treatment and storage of collected household water was measured on the basis of rates of diarrhoeal illness of household members.

As shown in Table 3 for the 8-month intervention study in Bangladesh, mean diarrhoea incidence rates for children <5 years of age were significantly lower ($P = 0.029$, t-test) in intervention households (20.8 episodes/1,000 days) than in control households (24.3 episodes/1,000 d). Diarrhoea rates calculated from aggregate data for all children <5 years of age were also lower in intervention households (19.6 episodes/1,000 d of observation) than in control households (24.9 episodes/1,000 d of observation). The incidence density ratio was 0.78 (95% CI 0.73–0.83) and the preventable fraction (reduction in diarrhoea incidence due to the intervention) was 20.8%.

In Bolivia, mean diarrhoea episodes/person for all age groups during the 6-month intervention period were significantly lower ($P = 0.002$) in intervention households (0.21) than in control households (0.38) (Table 4). Families without the intervention had about twice the risk of diarrhoea as families with the intervention, and about 43% of all cases of diarrhoea were preventable by the intervention. However, the magnitude of the protective effect of the intervention was not consistent for persons of all ages. While mean diarrhoea rates in children of ages 5–14 were significantly lower ($p = 0.01$) in the intervention group (0.12 episodes per person) than in the control group (0.29 episodes per person), the rates in children of ages 1–4 were only slightly lower in the intervention group (0.77) than in the control group (0.81).

Discussion

The results of these studies clearly document the ability of a simple system of manually chlorinating collected household water and storing it in a safe vessel to significantly improve the microbiological quality of the water and reduce waterborne diarrhoeal disease. The system was widely used, accepted and considered affordable by the participating communities based on compliance, acceptability and willingness to pay studies (data not shown) (Venczel, 1997; Handzel, 1998). The results of these studies are consistent with those of others documenting the ability of simple chlorination and storage in a safe vessel to improve the microbial quality of water and reduce diarrhoeal disease. As summarised in

Table 3 Diarrhoea incidence rates for children <5 years of age in intervention and control households in Bangladesh

Diarrhoea incidence rate	Intervention households	Control households
Mean episodes/1,000 d*	20.8	24.3
Aggregate rate/1,000 d**	19.6	24.8
Mean episodes of diarrhoea	3.5	4.1

* mean values of individual incidence rates; ** (total diarhhoeal episodes/total observation days) x1,000

Table 4 Mean diarrhoea rates for all ages in intervention and control households in Bolivia

Diarrhoea rates	Intervention	Control
Mean episodes/person	0.21	0.38
Mean episodes/household/month	1.25	2.20

Table 5 Efficacy of manual chlorination and storage in a specialized container to disinfect household water: disease reduction and improvement of microbial quality

Site	Storage	% disease reduction	Significant microbe reduction?	Reference
Saudi Arabia	Household tanks	48%, diarrhoea	Yes, *E. coli* +ve from 100% to 3%	Mahfouz *et al.*, 1995
India	Earthenware	17–7.3%, cholera	Cholera from 17% to 7%	Deb *et al.*, 1986
Zambia	Special* or local vessel	90%, cholera (during outbreak)	Yes, *E. coli* +ve from 95+% to 31%	Quick, R. *pers. comm.*
Madagascar	Special* and traditional vessels	90%, cholera (during outbreak)	Yes, median *E. coli* from 13 to 0/100 mL	Mong *et al.*, 2001; Quick, R. *pers. comm.*
Uzbekistan	Special* vessel	85%, diarrhoea	No data	Semenza *et al.*, 1998

* plastic (high-density polyethylene), about 20 L capacity, valved spigot to dispense water, 6–9 cm opening to fill and clean, handle to carry and reposition, and label with pictorial and written use instructions and hygiene education

Table 5, many studies have shown that the microbiological quality of stored household water can be significantly improved and diarrhoeal disease can be significantly reduced by adding chlorine to water stored in a household vessel in developing countries.

Simple and low cost systems to add chlorine to collected household water stored in a dedicated, narrow-mouth plastic container with a valved spigot have typically reduced waterborne microbes by >99% and reduced community diarrhoeal disease by as much as 20–50%. The best systems employ concentrated sodium hypochlorite solution that is added to household water stored in a specially designed, rectangular, plastic vessel (12–30 L) with a moderate size, screw cap opening for filling and cleaning and a separate valved spigot to dispense the treated, stored water. The treatment and storage technology is accompanied and supported by an education, motivation (through social marketing) and behaviour modification system to achieve community and household participation and to improve hygiene behaviour related to household water use. The extent to which improving drinking water quality at the household level reduces diarrhoeal disease probably depends on a variety of technology-related as well as site-specific environmental and demographic factors that require further investigation, characterisation and analyses.

Consumer education, participation and social marketing are considered essential and integral to achieving acceptance and sustainability for this and other household drinking water treatment systems. In addition, pilot and feasibility studies are also encouraged, as is economic, social and political support from donor agencies, non-governmental organisations, government agencies, the private sector and other sources. Such activities are recognised as essential for designing, mobilising for, implementing and assessing this and other water quality management systems at the household level.

Conclusions

Improvements in microbial quality and reductions in diarrhoeal and possibly other diseases are achieved using simple, accessible and low cost technologies to treat and safely store household water, such as the chlorination and special storage vessel system described here. Therefore, further development, refinement, implementation, evaluation and comparison of household water treatment and safe storage technologies is both justified and encouraged. Greater efforts to disseminate information about household water treatment and storage technologies and their benefits and advantages are needed at international, national and local levels. For a large part of the world's population currently lacking access to safe water, the use of an appropriate technology for household water, such as chlorination and storage in a special vessel, is likely to have beneficial effects in the form of reduced infectious disease and greater productivity. Furthermore, use of improved water treatment and storage at the household level is likely to increase personal and community knowledge and awareness of the importance of water hygiene and sanitation and the benefits that can be derived. Such awareness is likely to support and facilitate the ultimate goal of providing the entire World's population with community piped waters that are accessible, safe and affordable.

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References

Conroy, R.M, Elmore-Meegan, M., Joyce, T., McGuigan, K.G. and Barnes, J. (1996). Solar disinfection of drinking water and diarrhoea in Maasai children: a controlled field trial. *Lancet* (North American Edition), **348**(9043), 1695–1697.

Conroy, R.M., Meegan, M., Joyce, T., McGuigan, K. and Barnes, J. (1999). Solar disinfection of water reduces diarrhoeal disease: an update. *Arch Dis Childhood*, **81**(4), 337–338.

Deb, B.C., Sircar, B.K., Sengupta, P.G., De, S.P., Mondal, S.K., Gupta, D.N., Saha, N.C., Ghosh, S. Mitra, U. and Pal, S.C. (1986). Studies on interventions to prevent eltor cholera transmission in urban slums. *Bull. Wld. Hlth. Org.*, **64**(1), 127–131.

Esrey, S., Feachem, R. and Hughes, J. (1985). Intervention for the control of diarrhoeal diseases among young children: improving water supplies and excreta disposal facilities. *Bull. Wld. Hlth. Org.*, **63**, 757–772.

Esrey, S.A., Potash, J.B., Roberts, L. and Schiff, C (1991). Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis and trachoma. *Bull. Wld. Hlth. Org.*, **69**, 609–621.

Handzel, T. (1998). *The Effect of Improved Drinking Water Quality on the Risk of Diarrhoeal Disease in an Urban Slum of Dhaka, Bangladesh: A Home Chlorination Intervention Trial.* Ph.D. Dissertation, University of North Carolina, Chapel Hill, NC, USA, pp. 186.

Mahfouz, A.A., Abdel-Moneim, M., al-Erian, R.A. and al-Amari, O.M. (1995). Impact of chlorination of water in domestic storage tanks on childhood diarrhoea: a community trial in the rural areas of Saudi Arabia. *J. Trop. Med. Hyg.*, **98**(2), 126–130.

Mintz, E.D., Reiff, F.M. and Tauxe, R.V. (1995). Treatment and storage in the home: a practical new strategy to prevent waterborne disease. *J. Am. Med. Assoc.*, **273**(12), 948–953.

Mintz, E., Bartram, J., Lochery, P. and Wegelin, M. (2001). Not just a drop in the bucket: expanding access to point-of-use water treatment systems. *Am. J. Publ. Hlth.*, **91**(10), 1565–1570.

Mong, Y., Kaiser, R., Rasoatiana, D.I., Razafimbololona, I. and Quick, R.E. (2001). Impact of the safe water system on water quality in cyclone-affected communities in Madagascar. *Am. J. Publ. Hlth.*, **91**(10), 1577–1579.

Payment, P., Richardson, L., Siemiatycki, J., Dewar, M., Edwards, M. and Franco, E. (1991). A randomised trial to evaluate the risks of gastrointestinal disease due to consumption of drinking water meeting current microbiological standards. *Am. J. Publ Hlth.*, **81**, 703–708.

Payment, P., Siemiatycki, J., Richardson, L., Gilles, R., Franco, E. and Prevot, M. (1997). A prospective epidemiological study of gastrointestinal health effects due to the consumption of drinking water. *Int. J. Environ. Hlth Res.*, **7**, 5–31.

Quick, R.E. *et al.* (1996). Narrow-mouthed water storage vessels and *in situ* chlorination in a Bolivian community: a simple method to improve drinking water quality. *Am. J. Trop. Med. Hyg.*, **54**(5), 511–516.

Quick, R.E. *et al.* (1999). Diarrhoea prevention in Bolivia through point-of-use water treatment and safe storage: a promising new strategy. *Epidemiol. Infect.*, **122**(1), 83–90.

Reiff, F.M., Roses, M., Venczel, L., Quick, R. and Witt, V.M. (1995). Low-cost safe water for the world: a practical interim solution. *J. Publ. Hlth. Policy*, **17**(4), 389–408.

Semenza, J. C. *et al.* (1998). Water distribution system and diarrhoeal disease transmission: a case study in Uzbekistan. *Am. J. Trop. Med. Hyg.*, **59**(6), 941–946.

Venczel, L.V. (1997) *Evaluation and Application of a Mixed Oxidant Disinfection System for Waterborne Disease Prevention*. Ph.D. Dissertation, University of North Carolina, Chapel Hill, NC, USA, pp. 252.