Pot chlorination of shallow wells in a peri-urban community in Kenya: an effectiveness trial

Krista Vandermeer, Robert Dreibelbis, Daniel Obote Akoko and Richard D. Rheingans

ABSTRACT

The effectivenss of pot chlorination to continously treat shallow wells in a peri-urban community in Kisumu, Kenya, was evaluated. A total of 30 shallow wells used by local residents were identified. Half were randomly allocated to be treated by pot chlorination, while the remainder served as the control group. Residual free chlorine (RFC) and the presence of *Escherichia coli* (*E. coli*) were measured in all wells before chlorination and at repeated intervals over a 14-day period. Although there was a reduction in *E. coli* levels in the intervention wells post-chlorination, there was no difference in the percentage of wells in each group meeting WHO drinking water guidelines of 0 *E. coli* CFUs/100 ml on day 7 ($p = 0.444$) or day 14 ($p = 0.188$). While the intervention was associated with a statistically significant improvement in the percentage of chlorinated wells meeting the WHO guidelines for RFC of at least 0.5 mg/l (41.7%) compared to control wells on day 7 ($p = 0.010$), by day 14 there was no detectable difference between the two groups ($p = 0.444$). Pot chlorination of the shallow wells in this study did not improve the microbiological quality of well water to WHO drinking water standards and was not effective in maintaining the recommended RFC required for continuous disinfection.

Key words | Africa, faecal contamination, pot chlorination, residual free chlorine, well water

Krista Vandermeer
Richard D. Rheingans
London School of Hygiene and Tropical Medicine,
Keppel Street, London, WC1E 7HT,
UK

Robert Dreibelbis (corresponding author)
Department of International Health,
Johns Hopkins Bloomberg School of Public Health,
Johns Hopkins University, 615 N Wolfe Street,
Baltimore, Maryland 21215,
USA
and
Hubert Department of Global Health, Center for Global Safe Water, Rollins School of Public Health,
Emory University,
1518 Clifton Road, Room 767, Atlanta,
Georgia, 30322,
USA
E-mail: *rdreibel@jhsph.edu*

Daniel Obote Akoko
Tropical Institute of Community Health and Development, Great Lakes University of Kisumu,
PO BOX 2224, Kisumu, 40100,
Kenya

Richard D. Rheingans
Department of Environmental and Global Health,
Center for African Studies, Emerging Pathogens Institute, University of Florida,
Box 100188, 101 S. Newell Dr, Room 2148,
Gainesville, FL 32610,
USA

INTRODUCTION

It is estimated that approximately 11% of the world's 7 billion people do not have access to an improved source of drinking water (UNICEF/WHO 2012) and many more lack access to *safe* water as defined by the WHO *Guidelines for Drinking-water Quality* (WHO 2011). The vast majority of these people live in developing countries where diarrhoeal diseases, largely attributable to unsafe drinking water supplies, inadequate sanitation and poor hygiene, remain a leading cause of morbidity and mortality (Prüss *et al.* 2002; Lopez *et al.* 2006).

In peri-urban communities in low-income countries service gaps persist due to the difficulties and costs involved with expanding piped water supplies and many residents must collect drinking water at sources outside of the home (UNICEF/WHO 2012). Shallow dug wells provide an inexpensive and low-tech method for accessing groundwater in areas with high water tables and their use for drinking and other domestic purposes is common. These wells, however, are highly susceptible to microbiological contamination, especially when uncovered or not properly lined (ARGOSS 2001; Pritchard *et al.* 2007).

doi: 10.2166/washdev.2013.238

Water contamination of drinking water supplies has been categorized by the World Health Organization (WHO 1997) based on detectable thermotolerant (faecal) coliforms or *Escherichia coli* (*E. coli*) colony-forming units (CFUs) per 100 ml of drinking water and sources categorized as: conforming with guidelines (0 CFU/100 ml), low risk (1–10 CFU/100 ml), intermediate risk (11–100 CFU/100 ml), high risk (101–1,000 CFU/100 ml) and very high risk (>1,000 CFU/100 ml). *E. coli* is the recommended indicator of choice for drinking water (WHO 1997) and thus was used in this study as the indicator for faecal contamination.

Chlorination has proven to be an effective method of disinfection of drinking water supplies and has been widely used since the early 1900s (Garrett *et al.* 2008). The advent of centralized water treatment and distribution was a major contributor to morbidity and mortality declines in Europe and North America in the early twentieth century (Cutler & Miller 2005). For water intended for drinking, WHO (2011) currently recommends a minimum residual free chlorine (RFC) concentration at the point of delivery of 0.2 mg/l in normal circumstances or 0.5 mg/l to continuously kill pathogens in circumstances where there is a high risk for future contamination. Where there is a risk of cholera or an outbreak has occurred, the WHO (1996a) recommends maintaining an RFC of 1.0 mg/l.

With large numbers of people lacking access to piped distribution systems, source-based chlorination is often employed to improve water quality, although its effectiveness is questionable, especially in settings where there is a high risk of contamination post water collection. Jensen *et al.* (2003) found that, although chlorination at the source led to improvement in drinking water quality in the home, there was little effect on the incidence of childhood diarrhoea, while Rowe *et al.* (1998) and Luby *et al.* (2006) found that source-based shock chlorination methods in which large volumes of chlorine are added to a specific water source are not effective in improving the bacteriological quality of water from wells or maintaining consistent levels of chlorine protection.

Pot chlorination is commonly promoted as a treatment method for the disinfection of shallow wells, particularly in response to outbreaks of waterborne diseases, such as cholera (Cairncross & Feachem 1993, pp. 81–83; WHO 1996b; Skinner 2001; Cavallaro *et al.* 2011). A typical pot chlorinator consists of a porous vessel (plastic, ceramic or clay) containing a mixture of coarse sand and powdered chlorine, such as calcium hypochlorite. The vessel is suspended in the well and as the water combines with the chlorine powder, the chlorinated solution will leave the pot to mix with the water. The goal of pot chlorination is to achieve an adequate RFC concentration for disinfection of microorganisms and to provide sufficient residual protection so that water is not re-contaminated during collection, transport and storage.

In response to a series of cholera outbreaks in peri-urban areas surrounding Kisumu, Kenya, during 2007 and 2008, UNICEF advised the Kisumu Municipal Health Department (KMHD) to install clay pots filled with powdered chlorine into the shallow wells. Although originally intended as a temporary measure during outbreak control, pot chlorination of wells in Kisumu was repeated by the municipal government on many occasions. There remains, however, little evidence on the effectiveness of pot chlorination during disease outbreaks or for routine water disinfection. For example, during a cholera outbreak in Guinea-Bissau, Cavallaro *et al.* (2011) found that RFC levels above the WHO recommended 1 mg/l were sustained in only four out of 26 study wells for more than 24 hours and in only one well for over 48 hours. The authors, however, were unable to assess bacteriological contamination of the wells during chlorine treatment.

The overall objective of this study was to assess the effectiveness of pot chlorination for the treatment of shallow wells within a peri-urban setting by comparing the microbiological quality tested using *E. coli* as an indicator and RFC of water samples drawn from wells with and without pot chlorination over the course of two weeks of follow-up.

MATERIALS AND METHODS

The study area

The study was conducted in Obunga, a peri-urban community in Kisumu, Kenya. The area has a high water table and while there are several tap stands connected to the treated municipal distribution system, unprotected shallow hand-dug wells continue to be a widely used water source in the community.

Sample size and sample selection

Assuming that treatment by pot chlorination would be 70% effective in achieving an RFC of 0.5 mg/l or greater versus no effect in the control group, 95% confidence and 80% power, a total of 9 treatment wells and 9 control wells were required. The sample size was increased to 30 wells to improve the power to evaluate smaller differences and to allow for loss to follow-up. After defining a representative transect of the Obunga community, a total of 30 wells were identified, 15 of which were randomly assigned to receive pot chlorination.

Pot chlorination intervention

Pot chlorination was performed according to the KMHD protocol. Water was added to a porous 500 ml clay pot filled three-quarters with 65% calcium hypochlorite bleaching powder (Aquafit, India) to create a paste. The clay pot was then covered with a piece of woven polypropylene fabric, tethered and secured with rope and lowered into intervention wells, approximately 30 cm below the water surface. The well owners were instructed to wait 24 hours after the pot chlorinators had been introduced before drawing water.

Sample collection

Water samples were collected from each of the 30 shallow wells at baseline (time 0). After installing the pot chlorinators, water samples were collected from intervention wells after 30 minutes, 4 hours and again after 1, 2, 3, 5, 7, 10 and 14 days to evaluate the pattern of microbial contamination and RFC post-chlorination and after 7 and 14 days from the control wells (Table 1).

Chemical and microbiological analysis

The RFC concentration was measured immediately after collection of the water samples using the *N*,*N*-diethyl-phenylenediamine (DPD) colorimetric method (ColorQ Pro-7, LaMotte, Maryland, USA). *E. coli* was used as the indicator organism for faecal contamination (Edberg *et al.* 2000) and quantified using standard membrane filtration techniques. Three volumes of well water (1, 10 and 100 ml) were individually filtered through 0.45 μm pore size membrane filters (Fisherbrand, France) and the filters were then transferred to 50 mm Petri plates containing a sterile absorbent pad saturated with m-ColiBlue24 Broth (HACH, Colorado, USA). Plates were then incubated at 44.5 °C ± 0.5 °C for 24 hours and *E. coli* colonies were counted.

Data analysis

Bacterial counts in water samples tend to be distributed according to the log scale; therefore, *E. coli* counts were analysed after a $\log_{10}$ transformation. The median RFC was used to summarize the central value for both the control and intervention wells at each sampling point to account for the positive skew in the data.

The time trends were examined by plotting the geometric mean of the *E. coli* concentration and the median RFC against time. The student *t*-test (unpaired) was used to compare the geometric mean *E. coli* concentrations of the control and intervention groups at baseline and 7 and 14 days after implementing the intervention. Fisher's exact test was used to compare proportions of control and intervention

Table 1 | Sample collection and testing (as indicated by 'X') of intervention and control shallow wells

	Baseline	30 min	4 hours	1 day	2 days	3 days	5 days	7 days	10 days	14 days
Intervention wells:										
Microbiology	X	X	X	X	X	X		X	X	X
Free chlorine	X	X	X	X	X	X	X	X	X	X
Control wells:										
Microbiology	X							X		X
Free chlorine	X							X		X

wells meeting the WHO guidelines for each outcome measure. All statistical analysis was performed using STATA, version 10.1.

RESULTS

Microbiological quality of well water

The geometric mean *E. coli* contamination levels and 95% confidence intervals (CIs) for the control and intervention wells at baseline and at each sampling point are shown in Figure 1. At baseline, all of the wells in both the control and intervention groups were highly contaminated with *E. coli*. After implementing pot chlorination in the intervention wells, the *E. coli* counts from the water samples of the intervention group were substantially lower than the samples from the control group at each sampling point. Seven days post-intervention, the geometric mean *E. coli* count of the intervention group (21; 95% CI: 6–73) was statistically less than that of the control group (1033; 95% CI: 495–2157) at $p < 0.0001$. After 14 days, the *E. coli* count was again less for the intervention group (9; 95% CI: 3–27) compared to the control (806; 95% CI: 357–1820) at $p < 0.0001$.

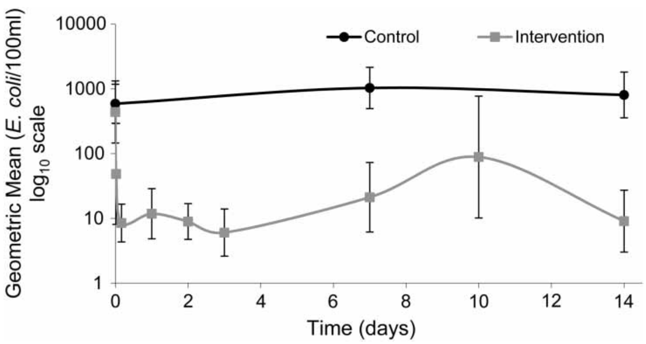

Figure 1 | Geometric mean *E. coli* counts (95% CI) by study group at baseline and each sampling point.

Table 2 presents the percentage of wells that fall into the WHO risk categories for faecal contamination (WHO 1997) at baseline, day 7 and day 14 of our study. At baseline, the proportion of wells with fewer than 10 *E. coli* CFUs/100 ml (conforming and low risk categories) was similar between control and intervention groups ($p = 0.224$). The intervention was associated with a statistically significant improvement in the percentage of wells meeting the low risk category after 7 ($p = 0.028$) and 14 days ($p = 0.001$). There was little to no evidence of a difference between the control wells and the intervention wells meeting the WHO guideline for drinking water of 0 *E. coli* CFUs/100 ml on day 7 ($p = 0.444$) or day 14 ($p = 0.188$) of the follow-up period.

Residual free chlorine (RFC)

At baseline, all wells had RFC levels below 0.2 mg/l, the absolute minimum level required for disinfection (Figure 2). After implementing pot chlorination in the intervention wells, the RFC levels in the water of the intervention wells

Table 2 | Number (and percentage) of wells by WHO risk category (in *E. coli* CFUs/100 ml)

	Control			Intervention		
Risk category *E. coli* CFUs/100 ml	**Baseline**	**Day 7**	**Day 14**	**Baseline**	**Day 7**	**Day 14**
Conforming 0	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (8%)	2 (17%)
Low risk 1–10	0 (0%)	0 (0%)	0 (0%)	1 (7%)	3 (25%)	5 (42%)
Intermediate risk 11–100	0 (0%)	2 (13%)	0 (0%)	2 (13%)	6 (50%)	3 (25%)
High risk 101–1,000	11 (77%)	4 (27%)	11 (73%)	7 (47%)	1 (8%)	2 (17%)
Very high risk >1,000	4 (23%)	9 (60%)	4 (27%)	5 (33%)	1 (8%)	0 (0%)

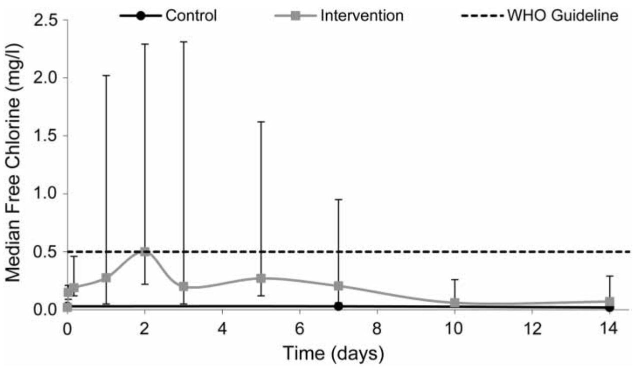

Figure 2 | Median residual free chlorine (LQ–UQ) by study group at baseline (time 0) and each sampling point over the 14-day follow-up period.

increased steadily and reached a maximum median RFC of 0.5 mg/l [Lower Quartile – Upper Quartile (LQ–UQ): 0.22–2.29] on day 2, after which time a consistent decline was observed. Two weeks after installing the pot chlorinators, the median RFC level in the intervention wells was 0.07 mg/l (LQ–UQ: 0.03–0.29), well below the WHO requirement of 0.5 mg/l (WHO 2011) for disinfection in situations where there is a risk for continuous contamination, such as the unprotected wells of this study.

During the 14-day follow-up period all of the control wells had an RFC of less than 0.5 mg/l (data not shown). Among the intervention wells, the highest percentage of wells (54%) with free chlorine of at least 0.5 mg/l occurred 2 days after installing the pot chlorinators, after which the percentage steadily decreased (Table 3). During the first 24 hours, only 13 and 20% of the wells had an RFC concentration of at least 0.5 mg/l after 30 min and 4 hours respectively, while 36% of the wells achieved an RFC concentration greater than 1.0 mg/l after 24 hours. On day 7, the intervention was associated with a statistically significant improvement in the percentage of wells meeting the WHO guideline for RFC of at least 0.5 mg/l (42%) compared to the control wells ($p = 0.010$). By day 14 there was little to no evidence of a difference between the control wells and the intervention wells meeting the free chlorine requirement for disinfection ($p = 0.444$).

DISCUSSION

In our study, pot chlorination resulted in a substantial decrease in the concentration of *E. coli* in the wells in the short term. However, at the end of the 14-day follow-up period, only 2 (17%) of the wells in the intervention group conformed to the WHO (2011) guideline of no *E. coli* bacteria in any 100 ml sample of water intended for human consumption and thus pot chlorination was not effective in sustaining improved microbiological quality of water in the wells to WHO drinking water standards.

Although pot chlorination improved the microbiological quality of the well water, it did not result in adequate levels of RFC needed to ensure disinfection and prevent recontamination. Not only is there a risk of contamination during collection, transportation and storage at the household level, but microbiological quality of shallow groundwater sources significantly deteriorates shortly after a heavy rainfall event (Howard *et al.* 2003). At the end of the 14-day follow-up period, 92% of wells had an RFC of less than 0.5 mg/l, the WHO guideline for disinfection, providing evidence that pot chlorination is ineffective at continuously protecting the water.

Several factors may have influenced the effectiveness of pot chlorination in our study, including the initial level of

Table 3 | Number (and percentage) of intervention wells by residual free chlorine (RFC) levels at each sampling point over the 14-day follow-up period

	Sampling point								
RFC (mg/l)	**0.5 h**	**4 h**	**1 d**	**2 d**	**3 d**	**5 d**	**7 d**	**10 d**	**14 d**
<0.5	13 (87%)	12 (80%)	8 (57%)	6 (46%)	7 (54%)	7 (54%)	7 (58%)	10 (83%)	11 (92%)
0.5–1.0	2 (13%)	3 (20%)	1 (7%)	2 (15%)	1 (8%)	1 (8%)	3 (25%)	1 (8%)	0 (0%)
>1.0	0 (0%)	0 (0%)	6 (36%)	5 (39%)	5 (38%)	5 (38%)	2 (17%)	1 (8%)	1 (8%)

contamination in the well, the volume of water in the well, the turbidity of the water and the imprecise release of chlorine from the pot chlorinators. Many of the wells in Obunga were at risk of continuous contamination with faecal matter, confirmed by the presence of *E. coli* in all of the wells at baseline and, therefore, not only is a long-term and effective treatment strategy required, but attempts should be made to improve the maintenance of the shallow wells and protect them from continuous contamination with faecal matter from nearby latrines and surface run-off.

It is also possible that the diffusion of chlorine from the pots may not be fast enough compared to the rate of water being drawn from the well and the incoming flow of fresh groundwater into the well, especially if the groundwater is contaminated. Rather than dosing each well according to volume, we used the KMHD pot chlorination protocol of standard disinfection product volumes irrespective of well size. This resulted in chlorine doses up to three times the recommended levels, yet these high doses still did not result in adequate RFC levels.

Applying the WHO drinking water standards to water sources in low-income urban communities from developing countries is sometimes regarded as too stringent (Cairncross & Feachem 1993, p. 32) and well water with a microbiological quality that meets the WHO low risk category may be more realistic. While the majority of the control and intervention wells consistently fell into the intermediate to high-risk categories, a larger percentage of the intervention wells fell into the low-risk category (≤10 *E. coli*/100 ml) compared to the control wells at day 7 and day 14 ($p = 0.028$ and 0.001, respectively), suggesting that pot chlorination is somewhat effective in attaining well water that is of lower risk to the community.

Our findings show an improved performance of pot chlorination compared to those of Cavallaro *et al.* (2011) in Guinea-Bissau. In their study, RFC levels exceeded 1 mg/l in 15% of sampled wells at 24 hours and only 4% at 48 hours compared to 36 and 39% of wells included in our study. RFC levels above the minimum recommended volume for non-outbreak periods were reached by over half of all wells in the Guinea-Bissau study by 24 hours; however, the authors noted a rapid decline in RFC levels in the post 24-hour period. In contrast, roughly half of all wells included in our study maintained RFC levels above 0.5 mg/l through day 7. The study by Cavallaro *et al.* (2011) was conducted during an active cholera outbreak, while our study occurred in a non-outbreak period. The outbreak may have resulted in greater than normal pathogen levels in the environment, thus leading to a faster decline in RFC levels than during our period of study.

The very short window of effective RFC observed in this study does not support the use of this intervention for continual disinfection and protection from subsequent recontamination, especially without continuous monitoring of RFC and bacteriological quality of the water and replacement of chlorine in the pots as needed. Frequent monitoring is generally not practical due to the time and cost required to do so (Cavallaro *et al.* 2011). The presence of pot chlorinators after they have become ineffective may present an additional risk to community members as it is perceived that the water is being treated at the source and additional household water treatment methods are not necessary.

Other methods of water treatment, more specifically point-of-use methods, have been shown to be very effective in improving the microbiological quality of water at the household level (Fewtrell *et al.* 2005; Clasen *et al.* 2007). The promotion of such interventions in conjunction with pot chlorination should be considered if the intention is to provide safe water for drinking purposes. Point-of-collection chlorination, such as chlorine dispensers, is another alternative treatment method to pot chlorination that ensures an accurate dose of chlorine for disinfection is added to each standard-sized water transport container and is more cost-effective than other low-cost approaches (Kremer *et al.* 2010).

CONCLUSIONS

Our study found that 14 days after the installation of pot chlorinators, there was no detectable difference in the percentage of wells meeting WHO drinking water guidelines of 0 *E. coli* CFUs/100 ml ($p = 0.188$) comparing intervention and control wells; nor was there a detectable difference between the percentage of chlorinated wells meeting the WHO guidelines for RFC of at least 0.5 mg/l compared to control wells ($p = 0.444$). These results suggest that pot chlorination was not an effective intervention for maintaining improvements in the microbiological quality of the well water to WHO drinking water standards or maintaining protective RFC concentrations. The substantial reductions in *E. coli* and improvements in RFC found in intervention wells in the first 48 hours after pot chlorinators were installed may help to reduce the risk of contaminated source water and provide residual protection for water subsequently stored in the home, especially during non-outbreak periods. However, the observed variability in performance and rapid declines in water quality and residual protection after 48 hours suggest that pot chlorination requires frequent monitoring of both RFC levels and microbiological quality to ensure that the hardware is performing as intended, limiting the practicality of pot chlorination for continuous disinfection. Other methods for long-term treatment at the source should be developed and promoted, such as chlorine dispensers or point-of-use treatment.

ACKNOWLEDGEMENTS

The authors wish to thank the Center for Global Safe Water at Emory University and the Emory University Global Health Institute for funding this work and the Red Cross for donating the clay pots. The views expressed are not necessarily those of the Center for Global Safe Water or the Red Cross. Special thanks to Lily Lukorito at Great Lakes University of Kisumu for her assistance with the laboratory analysis.

REFERENCES

ARGOSS 2001 Guidelines for assessing the risk to groundwater from on-site sanitation. British Geological Survey Commissioned Report CR/01/142.

Cairncross, S. & Feachem, R. 1993 *Environmental Health Engineering in the Tropics*, *an Introductory Text*, 2nd edn. John Wiley & Sons Ltd, West Sussex, England.

Cavallaro, E. C., Harris, J. R., da Goia, M. S., dos Santos Barrado, J. C., da Nobrega, A. A., de Alvarenga Junior, I. C., Silva, A. P., Sobel, J. & Mintz, E. 2011 Evaluation of pot-chlorination of wells during a cholera outbreak, Biassau, Guinea-Bissau, 2008. *J. Water Health* **9** (2), 394–402.

Clasen, T., Schmidt, W. P., Rabie, T., Roberts, I. & Cairncross, S. 2007 Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis. *Br. Med. J.* **334** (7957), 782–791.

Cutler, D. & Miller, G. 2005 The role of public health improvements in health advances: the twentieth-century United States. *Demography* **41** (1), 1–22.

Edberg, S. C., Rice, E. W., Karlin, R. J. & Allen, M. J. 2000 *Escherichia coli*: the best biological drinking water indicator for public health protection. *J. Appl. Microbiol.* **88**, 106S–116S.

Fewtrell, L., Kaufmann, R., Kay, D., Enanoria, W., Haller, L. & Colford, J. 2005 Water, sanitation and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *Lancet Infect. Dis*. **5**, 42–52.

Garrett, V., Ogutu, P., Mabonga, P., Ombeki, S., Mwaki, A., Aluoch, G., Phelan, M. & Quick, R. E. 2008 Diarrhoea prevention in a high-risk rural Kenyan population through point-of-use chlorination, safe water storage, sanitation, and rainwater harvesting. *Epidemiol. Infect*. **136**, 1463–1471.

Howard, G., Pedley, S., Barret, M., Nalubegda, M. & Johal, K. 2003 Risk factors contributing to shallow groundwater in Kampala, Uganda. *Water Res*. **37** (14), 3421–3429.

Jensen, P. K., Ensink, J. H. J., Jayasinghe, G., van der Hoek, W., Cairncross, S. & Dalsgaard, A. 2003 Effect of chlorination of drinking-water on water quality and childhood diarrhoea in a village in Pakistan. *J. Health Popul. Nutr*. **21** (1), 26–31.

Kremer, M., Ahuja, A. & Zwane, A. P. 2010 Providing safe water: evidence from randomized evaluations. Discussion Paper 2010–23, Harvard Environmental Economics Program, Cambridge, MA, USA.

Lopez, A. D., Mathers, C. D., Ezzati, M., Jamison, D. T. & Murray, C. J. L. 2006 *Global Burden of Disease and Risk Factors*. The World Bank and Oxford University Press.

Luby, S., Islam, M. S. & Johnston, R. 2006 Chlorine spot treatment of flooded tube wells, an efficacy trial. *J. Appl. Microbiol*. **100**, 1154–1158.

Pritchard, M., Mkandawire, T. & O'Neil, J. G. 2007 Biological, chemical and physical drinking water quality from shallow wells in Malawi: Case study of Blantyre, Chiradzulu and Mulanje. *Phys. Chem. Earth* **32** (15–18), 1167–1177.

Prüss, A., Kay, D., Fewtrell, L. & Bartram, J. 2002 Estimating the burden of disease from water, sanitation, and hygiene at a global level. *Environ. Health Perspect*. **110** (5), 537–542.

Rowe, A. K., Angulo, F. J., Roberts, L. & Tauxe, R. 1998 Chlorinating well water with liquid bleach was not an effective water disinfection strategy in Guinea-Bissau. *Int. J. Environ. Health Res*. **8**, 339–340.

Skinner, B. 2001 *Chlorinating Small Water Supplies – A Review of Gravity-Powered and Water-Powered Chlorinators*. LSHTM/WEDC, London and Loughborough, UK. Available from: http://www.lboro.ac.uk/well/resources/well-studies/full-reports-pdf/task0511.pdf (accessed 7 November 2012).

United Nations Children's Fund (UNICEF)/World Health Organization 2012 *Progress on Drinking Water and Sanitation: 2012 Update*. UNICEF/WHO Joint Monitoring Programme for Water Supply and Sanitation.

World Health Organization 1996a *Fact Sheets on Environmental Sanitation, Fact Sheet 2.17: Chlorine concepts*. World Health Organization, Geneva.

World Health Organization 1996b *Fact Sheets on Environmental Sanitation, Fact Sheet 2.21: Continuous chlorination of dug wells*. World Health Organization, Geneva.

World Health Organization 1997 *Guidelines for Drinking-Water Quality, 2nd Edition, Volume 3, Surveillance and Control of Community Supplies*. World Health Organization, Geneva.

World Health Organization 2011 *Guidelines for Drinking-Water Quality, 4th Edition*. World Health Organization, Geneva.

First received 30 November 2012; accepted in revised form 13 May 2013. Available online 2 July 2013