Tropical Medicine and International Health

VOLUME 9 NO 2 PP 187–191 FEBRUARY 2004

Editorial: **Household water management: refining the dominant paradigm**

Thomas F. Clasen and Sandy Cairncross

London School of Hygiene and Tropical Medicine, London, UK

keywords diarrhoea, drinking water, household, point of use, review, treatment

Diarrhoeal diseases kill an estimated 2.5 million people each year, the majority being children under 5 years (Kosek *et al.* 2003). An estimated 4 billion cases annually account for 5.7% of the global burden of disease and place diarrhoeal disease as the third highest cause of morbidity and sixth highest cause of mortality (Pruess *et al.* 2002). Among children under 5 years in developing countries, diarrhoeal disease accounts for 21% of all deaths (Parashar *et al.* 2003). By inhibiting normal consumption of foods and adsorption of nutrients, diarrhoeal diseases are also an important cause of malnutrition, leading to impaired physical growth and cognitive development (Guerrant *et al.* 1999), reduced resistance to infection (Baqui *et al.* 1993) and potentially long-term gastrointestinal disorders (Schneider *et al.* 1978).

Infectious agents associated with diarrhoeal disease are transmitted chiefly through the faecal-oral route (Byers *et al.* 2001). A wide variety of bacterial, viral and protozoan pathogens excreted in the faeces of humans and animals are known to cause diarrhoea. Many of these are potentially waterborne – transmitted through the ingestion of contaminated water (Leclerc *et al.* 2002). Accordingly, a number of interventions have been developed to treat water. These include (i) physical removal of pathogens (e.g. filtration, adsorption and sedimentation); (ii) chemical treatment (e.g. assisted sedimentation, chemical disinfection and ion exchange); or (iii) heat and ultra violet (UV) radiation. Because of the risk of recontamination (Clasen & Bastable 2003), interventions to improve water quality also include steps to maintain the microbiological quality of safe drinking water, such as piped distribution, residual disinfection and improved storage. These efforts are expected to receive additional priority as a result of the United Nation's commitment to reduce by one-half of the 1.5 billion people without sustainable access to improved water, one of the United Nation's Millennium Development Goals (United Nations 2000), and by the World Health Organization's steps to accelerate the health gains of safe water to the remaining population by improved treatment and storage of water at the household level (Sobsey 2002).

Health authorities generally accept that safe water plays an important role in preventing outbreaks of diarrhoeal disease (Hunter 1997). Accordingly, the most widely accepted standard for water quality allows no detectable level of harmful pathogens at the point of distribution (WHO 1993). However, in those settings in which diarrhoeal disease is endemic, much of the epidemiological evidence for increased health benefits following improvements in the quality of drinking water has been equivocal (Esrey & Habicht 1986; Lindskog *et al.* 1987; Cairncross 1989). As many of these same waterborne pathogens are also transmitted via ingestion of contaminated food and other beverages, by person-to-person contact, and by direct or indirect contact with infected faeces, improvements in water quality alone may not necessarily interrupt transmission (Briscoe 1984).

As a result of this variety of risk factors, interventions for the prevention of diarrhoeal disease not only include enhanced water quality but also steps to (i) improve the proper disposal of human faeces (sanitation), (ii) increase the quantity and improve access to water (water supply), and (iii) promote hand washing and other hygiene practices within domestic and community settings (hygiene). As in the case of studies of water quality, there is a wide range in the reported measure of effect on diarrhoea morbidity of each of these other environmental interventions (Esrey *et al.* 1985). Even more fundamentally, there are also questions about the methods and validity of studies designed to assess the health impact of such interventions (Briscoe *et al.* 1986; Imo State Evaluation Team 1989).

As part of a larger evaluation of interventions for the control of diarrhoeal disease (Feachem *et al.* 1983), Esrey *et al.* (1985) reviewed 67 studies to determine the health impact from improvements in water supplies and excreta disposal facilities (Esrey *et al.* 1985). The median reduction in diarrhoeal morbidity from improved water quality was 16% (range 0–90%). This compared with 22% for

© 2004 Blackwell Publishing Ltd

improvements in excreta disposal, 25% for improvements in water availability and 37% for combined improvements in water quality and availability. In 1991, the review was updated and expanded to cover 144 studies addressing a variety of specific pathogens associated with poor water and sanitation (Esrey *et al.* 1991). The median reduction in diarrhoeal disease from improvements in water quality from which calculations could be made was 17% (15% from studies the authors deemed rigorous), compared with 22% (36%) for sanitation, 27% (20%) for water quantity, 20% (30%) for combined water and sanitation, 33% (33%) for hygiene and only 16% (17%) for combined water quality and quantity.

These reviews led to league tables that established a simple and understandable priority to environmental health interventions for preventing diarrhoeal disease. Ubiquitously cited in both professional journals and practical guides, the reviews have led to the dominant paradigm respecting water supply and sanitation interventions: that to achieve broad health impact, greater attention should be given to safe excreta disposal and proper use of water for personal and domestic hygiene rather than to drinking-water quality. The corollary has become equally established: that interventions aimed solely at improving drinking water quality would have relatively little impact in reducing diarrhoeal disease.

There is, however, increasing evidence that has begun to call into question, the validity of the dominant paradigm. The first body of evidence, although admittedly indirect, should nevertheless give pause to those working on environmental interventions to reduce diarrhoeal disease. While substantial progress has been made over the last decade in reducing the mortality associated with diarrhoeal disease, morbidity remains essentially unchanged (Kosek *et al.* 2003). Although there has been substantial success from interventions to improve case management, such as oral rehydration therapy, the dominant paradigm and the priority it establishes with respect to water and sanitation initiatives has not led to corresponding success in reducing transmission of the pathogenic agents (Huttly *et al.* 1997).

The second body of evidence stems from a relatively new approach to enhancing water quality as part of a public health initiative: improved household water management. While the extent to which even safe water becomes faecally contaminated during collection, transport, storage and drawing in the home is well known (Wright *et al.* 2003), only recently have low-cost health interventions been promoted to improve and preserve water quality at the household level (Mintz *et al.* 2001). Based on a comprehensive review of these interventions, the WHO concluded that there was now 'conclusive evidence that simple, acceptable, low-cost interventions at the household and community level are capable of dramatically improving the microbial quality of household stored water and reducing the attendant risks of diarrhoeal disease and death' (Sobsey 2002). This has lead to the formation of the WHO-sponsored International Network for the Promotion of Safe Household Water Treatment and Storage, a global collaboration of UN and bilateral agencies, NGO's, research institutions and the private sector committed to improved household water management as a component in water, sanitation and hygiene programmes.

Interventions at the household level may, in fact, represent an exception to the dominant paradigm. None of the studies that Esrey *et al.* examined for their conclusions regarding the impact of water quality reflected interventions at the point of use. A brief analysis of 21 controlled field trials over the last 20 years dealing specifically with interventions designed to enhance the microbiological quality of drinking water at the household level showed a median reduction in endemic diarrhoeal disease of 42% compared with the control groups (Clasen 2003). The result was fairly consistent regardless of the nature of the intervention. Nine studies using free chlorine produced a median reduction of 46% (Kirchhoff *et al.* 1985; Deb *et al.* 1986; Mahfouz *et al.* 1995; Handzel 1998; Semenza *et al.* 1998; Quick *et al.* 1999, 2002; Sobsey *et al.* 2003); five studies examining filtration had a median reduction of 40% (Payment *et al.* 1991; Hellard *et al.* 2001; Clasen *et al.* 2003; Colwell *et al.* 2003); three studies employing flocculation or a combination of flocculation and disinfection showed a median reduction of 38% (Luby *et al.* 2003; Reller *et al.* 2003; Kahn *et al.* 1984), and four studies of heat or solar radiation produced a median reduction of 35% (Conroy *et al.* 1996, 1999; Conroy *et al.* 2001; Iijima *et al.* 2001). Only 2 of the 21 intervention studies showed no statistically significant reduction when compared with controls (Kirchhoff *et al.* 1985; Hellard *et al.* 2001). Nevertheless, it must be said that these studies have not yet been systematically scrutinized to arrive at a pooled measure of effect, to explore potential heterogeneity or to evaluate other possible explanations such as differences in ambient water quality or in the population's hygiene and sanitation practices.

Another possible reason for the difference between these reported results and the 15–17% median reduction predicted by Esrey *et al.* is the methodology employed. Esrey *et al.* based their conclusions chiefly on observational studies. In addition to the confounding and bias inherent in such studies, significant and widespread methodological problems with these studies have been pointed out (Blum & Feachem 1983; Esrey & Habicht 1986). Although these previous reviews were helpful in identifying the broad

 © 2004 Blackwell Publishing Ltd

questions and suggested answers, they did not employ the more rigorous methodologies and statistical methods, including meta analysis, of a systematic review (Egger *et al.* 2001). In terms of coverage, for example, neither review involved a comprehensive search strategy (Clarke & Oxman 2003). Accordingly, the conclusions with respect to water quality are based on a limited number of studies, and omitted a number of studies that appear to have met the inclusion criteria. The reviews were also limited to studies in the English language. With respect to statistical methods, the simple use of the median fails to take into account the size of the study and the variance observed in the results, factors that are weighted in meta-analysis to arrive at a pooled measure of effect (Deeks *et al.* 2001). Moreover, they do not distinguish between the various case definitions (Moy *et al.* 1991) and measures of diarrhoea morbidity (Morris *et al.* 1996; Pickering *et al.* 1987). In addition, while Esrey attempted to incorporate quality criteria in the reviews, there was no independent assessment of study quality or, for that matter, whether identified studies met the inclusion criteria (Juni *et al.* 2001). Furthermore, these prior reviews did not explore publication bias and sensitivity.

Some of these areas are addressed by a more recent review (Gundry *et al.* 2003). Unfortunately, however, this review also relies heavily on observational studies, does not include a number of studies that would appear to meet the investigators' inclusion criteria, and otherwise fails to follow many of the procedures for disciplined systematic reviews recommended by the Cochrane Collaboration and its Infectious Diseases Review Group. The authors, together with colleagues at the London School of Hygiene and Tropical Medicine, have filed a protocol with the Cochrane Collaboration to undertake such a review (T. Clasen *et al.* in preparation).

In the final analysis, it seems most likely that the dominant paradigm may not be so much wrong as incomplete. While Esrey's league tables comparing the relative impact of various types of environmental interventions are enticingly simple, they fail to explain the potentially more important reasons for the broad differences within each type. In the case of water quality improvements, for example, Esrey cited a median reduction in diarrhoea disease from 9 studies of 16%, with a range in effect from 0% to 90%. The real headline—and what should have captured the attention of subsequent researchers—was this range and its possible explanations. Studies have demonstrated significant differences in diarrhoea morbidity because of differences in case definitions, recall periods for reporting episodes, reported *vs.* clinically confirmed cases, age, seasonality, ambient level of contamination, and pathogenicity of the aetiological agents (Byers *et al.* 2001). Analysis of sub-groups, such as the specific type of intervention, the point at which it is applied (e.g. point of supply *vs.* point of use), and whether or not the intervention includes components in addition to improved water quality (e.g. sanitation, hygiene promotion, improved supply, safe storage) may also be important (Mintz *et al.* 2001).

The encouraging results from studies of improved household water management provide a sufficient impetus for reexamining the potential health impact of interventions to improve drinking water quality. They also provide an important opportunity to investigate more subtle but potentially important differences in the environmental health interventions and the manner in which their impact is assessed. Understanding the reasons for the heterogeneity in the observed effect – a primary objective in disciplined systematic reviews – and the differences in key sub-groups should lead to more accurate predictions of the true effect that can be expected under the vastly different contextual circumstances presented in a particular disease setting from the type of intervention employed (Petitti 2000). This type of analysis should ultimately help refine the dominant paradigm, and lead to more focused guidance on the potential health impact of water quality interventions.

References

Baqui AH, Black RE, Sack RB, Chowdhury HR, Yunus M & Siddique AK (1993) Malnutrition, cell-mediated immune deficiency and diarrhoea: a community-based longitudinal study in rural Bangladeshi children. *American Journal of Epidemiology* **137**, 355–365.

Blum D & Feachem RG (1983) Measuring the impact of water supply and sanitation investments on diarrhoeal diseases: problems in methodology. *International Journal of Epidemiology* **12**, 357–365.

Briscoe J (1984) Intervention studies and the definition of dominant transmission routes. *American Journal of Epidemiology* **120**, 449–455.

Briscoe J, Feachem RG & Rahaman MM (1986) *Evaluating Health Impact: Water Supply, Sanitation, and Hygiene Education*. International Development Research Centre, Ottawa.

Byers KE, Guerrant RL & Farr BM (2001) Chapter 11: Fecal-Oral Transmission. In: *Epidemiologic Methods for the Study of Infectious Diseases* (eds Thomas JC & Webber DJ) Oxford University Press, Oxford, pp. 228–248.

Cairncross S (1989) Water supply and sanitation: an agenda for research. *Journal of Tropical Medicine and Hygiene* **92**, 301–314.

Clarke M & Oxman AD (eds) (2003) Optimal search strategy. Cochrane Reviewers' Handbook 4.2.0 (updated March 2003); Appendix 5c. In: *The Cochrane Library (database on disk and CDROM)*. The Cochrane Collaboration. Wiley, Chichester.

© 2004 Blackwell Publishing Ltd

Clasen T (2003) Disease reduction through household water treatment. Paper presented at the IWA/WHO International Symposium on Health-Related Water Microbiology, Cape Town, South Africa, 14–19 September 2003.

Clasen T & Bastable A (2003) Faecal contamination of drinking water during collection and household storage: the need to extend protection to the point of use. *Journal of Water and Health* **1**, 109–115.

Clasen T, Roberts I, Rabie T & Cairncross S (2003) Interventions to improve water quality for preventing infectious diarrhoea (Protocol for a Cochrane Review). In: *The Cochrane Library*. The Cochrane Collaboration, Oxford.

Colwell RR, Huq A, Islam MS *et al.* (2003) Reduction of cholera in Bangladeshi villages by simple filtration. *Proceedings of the National Academy of Sciences of the United States of America* **100**, 1051–1055.

Conroy RM, Elmore-Meegan M, Joyce T, McGuigan KG & Barnes J (1996) Solar disinfection of drinking water and diarrhoea in Maasai children: a controlled field trial. *Lancet* **348**, 1695–1697.

Conroy RM, Meegan ME, Joyce T, McGuigan K & Barnes J (1999) Solar disinfection of water reduce diarrhoeal disease: an update. *Archives of Disease in Childhood* **81**, 337–338.

Conroy RM, Meegan ME, Joyce T, McGuigan K & Barnes J (2001) Solar disinfection of drinking water protects against cholera in children under 6 years of age. *Archives of Disease in Childhood* **85**, 293–295.

Deb BC, Sircar BK, Sengupta PG *et al.* (1986) Studies on interventions to prevent eltor cholera transmission in uran slums. *Bulletin of the World Health Organization* **64**, 127–131.

Deeks JJ, Altman DG & Bradburn MJ (2001) Statistical methods for examining heterogeneity and combining results from several studies in meta-analysis. In: *Systematic Reviews in Health Care*, 2nd edn. BMJ Books, London, pp. 285–312.

Egger M, Smith GD & Altman DG (eds) (2001) *Systematic Reviews in Health Care: Meta-Analysis in Context*. BMI Books, London.

Esrey SA & Habicht J-P (1986) Epidemiologic evidence for health benefits from improved water and sanitation in developing countries. *Epidemiologic Reviews* **8**, 117–128.

Esrey SA, Feachem RG & Hughes JM (1985) Interventions for the control of diarrhoeal diseases among young children: improving water supplies and excreta disposal facilities. *Bulletin of the World Health Organization* **64**, 776–772.

Esrey SA, Potash JB, Roberts L & Shiff C (1991) Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and tracoma. *Bulletin of the World Health Organization* **69**, 609–621.

Feachem RG, Hogan RC & Merson MH (1983) Diarrhoeal disease control; reviews of potential interventions. *Bulletin of the World Health Organization* **61**, 637–640.

Guerrant DI, Moore SR, Lima AAM, Patrick P, Schorling JB & Guerrant RL (1999) Association of early childhood diarrhoea and cryptosporidiosis with impaired physical fitness and cognitive function four-seven years later in a poor urban community in Northeast Brazil. *American Journal of Tropical Medicine and Hygiene* **61**, 707–713.

Gundry S, Wright J & Conroy R (2003) A systematic review of the health outcomes related to household water quality in developing countries. *Journal of Water and Health* (in press).

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. Doctoral Dissertation. Department of Environmental Sciences and Engineering, University of North Carolina, Chapel Hill, UNC, 186 pp.

Hellard ME, Sinclair MI, Forbes AB & Fairley CK (2001) A randomized, blinded, controlled trial investigating the gastrointestinal health effects of drinking water quality. *Environmental Health Perspectives* **109**, 773–778.

Hunter PR (1997) *Waterborne Disease Epidemiology and Ecology*. John Wiley and Sons, Chichester.

Huttly SR, Morris SS & Pisani V (1997) Prevention of diarrhoea in young children in developing countries. *Bulletin of the World Health Organization* **75**, 163–174.

Iijima Y, Karama M, Oundo JO & Honda T (2001) Prevention of bacterial diarrhoea by pasteurization of drinking water in Kenya. *Microbiology and Immunology* **45**, 413–416.

Imo State Evaluation Team (1989) Evaluation water and sanitation projects: lessons from Imo State, Nigeria. *Health Policy and Planning* **4**, 40–49.

Juni P, Altman DG & Egger M (2001) Systematic reviews in health care: Assessing the quality of controlled trials. *British Medical Journal* **323**, 42–46.

Kahn MU, Kahn MR, Hossain B & Ahmed QS (1984) Alum potash in water to prevent cholera. *Lancet* **2**, 1032.

Kirchhoff LV, McClelland KE, Do Carmo Pinho M, Araujo JG, De Sousa MA & Guerrant RL (1985) Feasibility and efficacy of in-home care chlorination in rural North-eastern Brazil. *Journal of Hygiene (London)* **94**, 173–180.

Kosek M, Bern C & Guerrant RL (2003) The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. *Bulletin of the World Health Organization* **81**, 197–204.

Leclerc H, Schwartzbrod L & Dei-Cas E (2002) Microbial agents associated with waterborne diseases. *Critical Reviews in Microbiology* **28**, 371–409.

Lindskog U, Lindskog P & Wall S (1987) Water supply, sanitation and health education programmes in developing countries: problems of evaluation. *Scandinavian Journal of Social Medicine* **15**, 123–130.

Luby S, Chiller TM, Mendoza CE *et al.* (2001) A randomised health outcome trial of a household-based flocculant-disinfectant for drinking water treatment. Paper presented at the IWA/WHO International Symposium on Health-Related Water Microbiology, Cape Town, South Africa, 14–19 September 2003.

Mahfouz AA, Abdel-Moneim M, al-Erain RA & al-Amari OM (1995) Impact of chlorination of water in domestic storage tanks on childhood diarrhoea: a community trial in the rural areas of Saudi Arabia. *Journal of Tropical Medicine and Hygiene* **98**, 126–130.

 © 2004 Blackwell Publishing Ltd

Mintz E, Bartram J, Lochery P & Wegelin M (2001) Not just a drop in the bucket: expanding access to point-of-use water treatment systems. *American Journal of Public Health* **91**, 1565–1570.

Morris SS, Cousens SN, Kirkwood BR, Arthur P & Ross DA (1996) Is prevalence of diarrhea a better predictor of subsequent mortality and weight gain than diarrhea incidence? *American Journal of Epidemiology* **144**, 582–588.

Moy RJD, Booth IW, McNeish AS & Choto RG (1991) Definitions of diarrhoea. *Journal of Diarrhoeal Diseases Research* **9**, 335.

Parashar UD, Bresee JS & Glass RI (2003) The global burden of diarrhoeal disease in children. *Bulletin of the World Health Organization* **81**, 236.

Payment P, Richardson L, Siemiatycki J, Dewar R, Edwardes M & Franco E (1991) A randomized trial to evaluate the risk of gastrointestinal disease due to consumption of drinking water meeting current microbiological standards. *American Journal of Public Health* **81**, 703–708.

Petitti DB (2000) *Meta-Analysis, Decision Analysis, and Cost-Effectiveness Analysis: Methods for Quantitative Synthesis in Medicine*, 2nd edn. Oxford University Press, New York.

Pickering H, Hayes R, Tomkins A, Carson D & Dunn D (1987) Alternative measures of diarrhoeal morbidity and their association with social and environmental factors in urban children in the Gambia. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **81**, 853–859.

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

Quick RE, Venczel LV, Mintz ED *et al.* (1999) Diarrhoea prevention in Bolivia through point-of-use water treatment and safe storage: a promising new strategy. *Epidemiology and Infection* **122**, 83–90.

Quick RE, Kimura A, Thevos A *et al.* (2002) Diarrhea prevention through household-level water disinfection and safe storage in Zambia. *American Journal of Tropical Medicine and Hygiene* **66**, 584–589.

Reller ME, Mendoza CE, Lopez MB *et al.* (2003) A randomized controlled trial of household-based flocculant-disinfectant drinking water treatment for diarrhea prevention in rural Guatemala. *American Journal of Tropical Medicine and Hygiene* **64**, 411.

Schneider RE, Shiffman M & Faigenblum J (1978) The potential effect of water on gastrointestinal infections prevalent in developing countries. *American Journal of Clinical Nutrition* **31**, 2089–2099.

Semenza JC, Roberts L, Henderson A, Bogan J & Rubin CH (1998) Water distribution system and diarrhoeal disease transmission: a case study in Uzbeckistan. *American Journal of Tropical Medicine and Hygiene* **59**, 941–946.

Sobsey MD (2002) *Managing Water in the Home: Accelerated Health Gains from Improved Water Supply*. (WHO/SDE/WSH/02.07) WHO, Geneva.

Sobsey MD, Handzel T & Venczel L (2003) Chlorination and safe storage of household drinking water in developing countries to reduce waterborne disease. *Water Science and Technology* **47**, 221–228.

United Nations (2000) United Nations Millennial Declaration. General Assembly Res. 55/2 (18 September 2000).

WHO (1993). *Guidelines for Drinking-Water Quality, Vol. 1, Recommendations*. WHO, Geneva.

Wright J, Gundry S & Conroy RM (2003) Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Tropical Medicine and International Health* (in press).

Authors

Thomas F. Clasen (corresponding author) and **Sandy Cairncross**, London School of Hygiene and Tropical Medicine, Keppel Street, London, WC1E 7HT, UK. E-mail: thomas.clasen@lshtm.ac.uk, sandy.cairncross@lshtm.ac.uk

© 2004 Blackwell Publishing Ltd