

A systematic review of the health outcomes related to household water quality in developing countries

Stephen Gundry, Jim Wright and Ronan Conroy

ABSTRACT

In developing countries, the microbial contamination of household drinking water is implicated in the prevalence of various diseases. This systematic review is concerned with two health outcomes, general diarrhoea and cholera, and their relationship with water quality at point-of-use. Observational studies investigating this relationship are reviewed, as well as studies of home water treatment and storage interventions. For cholera, a clear relationship was found with contaminated water. Home water treatment and storage interventions were also found to reduce cholera. For general diarrhoea, no clear relationship was found with point-of-use water quality, although interventions did significantly reduce diarrhoeal incidence. Reasons for these apparently contradictory results concerning general diarrhoea are discussed and suggestions for further research offered. The policy implications of the findings are also discussed.

Key words | coliform bacilli, developing countries, diarrhoea, meta-analysis, water microbiology

Stephen Gundry (corresponding author)
Jim Wright
 Water and Environmental Management Research Centre,
 University of Bristol,
 83 Woodland Road,
 Bristol BS8 1US,
 UK
 Tel: +44-117-954-5294
 Fax: +44-117-954-5389
 Email: stephen.gundry@bristol.ac.uk
 Home page: <http://www.bristol.ac.uk/aquapol>

Ronan Conroy
 Royal College of Surgeons in Ireland,
 Dept of Epidemiology & Public Health Medicine,
 Mercer Building, Mercer Street Lower,
 Dublin 2,
 Eire

INTRODUCTION

Esrey *et al.* (1985, 1991) and Esrey (1996) analysed the relative contributions of different interventions to reductions in diarrhoea. One intervention, 'improving water quality', is shown to have a much lower effect than other interventions such as sanitation, personal hygiene (e.g. hand washing) and increasing water quantity. However, these reviews focus upon *source* water quality improvements rather than improvements at *point-of-use*. A recent comprehensive review of storage and treatment of household water (Sobsey 2002) recognises the need for more field testing of various interventions that have shown promise in the laboratory. This systematic review assesses the results of published field research in this area.

In many developing countries, potable water is collected from communal sources which are either unimproved (e.g. unprotected wells, unprotected springs, and rivers) or improved (e.g. protected wells, boreholes and public standpipes) (WHO/UNICEF, 2000). Such sources can be substantial distances from the households, particularly in rural areas. Microbial contamination of

domestic drinking water during and after collection from the source has been recognised as a problem for such households, occurring even where the water sources are uncontaminated. Such post-source contamination results in poorer water quality in storage vessels within households.

Some have argued that this post-source contamination may negate the health benefits of new water source installations (Musa *et al.* 1999). In contrast, Vanderslice & Briscoe (1993) have argued that other faecal-oral routes, such as pathogens consumed in food or dirty hands, may be more important than drinking water in causing disease. These authors argue that immunity is acquired to familial pathogens through repeated exposure, but as such immunity does not protect against source pathogens, these are a greater risk to health. However, this argument ignores the fact that immunity to familial pathogens develops slowly and, as a result, post-source contamination may still affect the health of very young children, especially during weaning.

This debate is of direct relevance to policy formulation and in particular the initiatives needed to halve the proportion of people without sustainable access to safe drinking water by 2015 under the Millennium Development Goals (MDG). If contamination of water after collection has little or no impact on health outcomes, a continued emphasis on new water sources seems justified. If, however, water contamination post-source does affect health, a greater emphasis on improving water quality at point-of-use is warranted, by promoting better water handling, storage and treatment. A greater emphasis on point-of-use interventions may be necessary not only to achieve the MDG for sustainable access to safe water, but also the MDG to reduce under-five mortality by two thirds by 2015.

This systematic review is concerned with two health outcomes, general diarrhoea and cholera, and their relationship with water quality at point-of-use. In the studies reviewed, the effects of stored water quality on health have been assessed in two ways: by comparing indicator and *V. cholerae* bacteria counts in stored water samples with general diarrhoea and cholera morbidity, and by assessing the health outcomes of intervention studies of home water treatment and storage.

METHODS

Criteria for inclusion

The review considers studies of any age group in developing countries where water is transported from a source outside the home and then stored within the household. Temporary residents (e.g. refugees in camps, tourists and military personnel) are excluded from the review as these settings may reflect abnormal water use and hygiene behaviours. The health outcomes included are restricted to general diarrhoea and cholera. Although several studies have assessed other health impacts of microbiological water quality (e.g. skin infections (Verweij *et al.* 1991)), these studies are too few to make any meaningful generalisations. This review does not cover the effects of chemical contaminants such as arsenic. The scope of the review is further restricted to studies that have collected health

information specific to the sample households, rather than using aggregated secondary statistics from health centres where data quality is uncertain. Studies relating government health statistics for broad areas to routine water quality monitoring results are therefore excluded.

The studies included for review have been divided into two categories:

1. *Observational studies that relate microbiological indicators of water quality at point-of-use to health outcomes.*

For example, such a study might assess the relationship between number of thermotolerant coliforms in point-of-use water and general diarrhoea morbidity among young children.

2. *Intervention studies that assess the effect of changes in water storage and/or treatment on health outcomes.*

These are all interventions that relate to the treatment or storage of water within the household, such as chlorination, solar disinfection, or improved storage vessels. Interventions affecting community water supplies, rather than those of individual households, are excluded from the review (e.g. installing a new borehole).

Search strategy for identification of studies

The search for relevant literature was primarily through on-line bibliographic databases (PubMed, Web of Science and the African Index Medicus). Abstracts highlighted by key word searches were scanned for relevance and photocopied as necessary. The so-called 'ancestry approach', in which references from key papers are systematically traced, was also used for two previous review papers (Vanderslice & Briscoe 1993; Mintz *et al.* 1995). In addition, several of the major journals and conference series were hand-searched for relevant articles. Publications searched in this manner included the *Journal of Diarrhoeal Diseases*, the WEDC conference series from 1994 onwards, *Waterlines*, and *Dialogue on Diarrhoea Research*. In terms of language, the search was restricted to papers published in English, French or Spanish and in terms of publication date, to papers published up to the

beginning of the year 2001. In some cases, results were published in too brief a form to be usable for the review. In such cases, an attempt was made to contact the authors to obtain further details of their results. Furthermore, key non-governmental organisations involved with household water treatment were contacted to identify intervention studies, but none of the studies submitted met the criteria for inclusion.

Abstracts and other details of relevant studies were collated in a bibliographic database and study design and setting characteristics were recorded in a spreadsheet, which was then exported to a statistical package (Stata) for meta-analysis.

Statistical methods

The statistical methods applied to the two types of studies were as follows:

1. *Observational studies that relate microbiological indicators of water quality at point-of-use to health outcomes.*

In most studies analysing the effects of water quality on health, subjects were classified into two groups, those with high quality stored water and those with low quality stored water. Differences in health outcomes between these high and low quality water groups were then expressed as odds ratios based on the number of diarrhoea or cholera cases in each group.

For general diarrhoea, the basis of this classification of water quality varied from study to study, because of differences in the analysis and reporting of results. High quality water was variously defined as those samples that tested negative for indicator bacteria (Lloyd-Evans *et al.* 1984; Genthe *et al.* 1997), those samples with bacteria counts below the median for the study (Henry *et al.* 1990), those samples with bacteria counts below 10 (Rajasekaran *et al.* 1977; Esrey *et al.* 1986) and those with thermotolerant coliform counts below 10,000 (Henry & Rahim 1990). The included studies used either *E. coli* (Black *et al.* 1982; Lloyd-Evans *et al.* 1984; Echeverria *et al.* 1987; Genthe *et al.* 1997) or

thermotolerant coliforms as indicator bacteria (Rajasekaran *et al.* 1977; Esrey & Habicht, 1986; Henry & Rahim, 1990; Henry *et al.* 1990; Han *et al.* 1991; Knight *et al.* 1992; Vanderslice & Briscoe, 1993; Genthe *et al.* 1997; Jagals *et al.* 1997). Several of these studies also presented data on the relationship between total coliforms and general diarrhoea (Lloyd Evans *et al.* 1984; Genthe *et al.* 1997; Jagals *et al.* 1997). These results were not analysed here, since total coliforms are known to be unreliable as an indicator of faecal contamination (WHO 2002). No studies were identified that assessed the relationship between enterococci at point-of-use and diarrhoea, despite evidence that levels of enterococci in source water are correlated with diarrhoea prevalence (Moe *et al.* 1991).

For cholera studies, low quality water was invariably defined as those stored water samples testing positive for *V. cholerae* bacteria.

2. *Intervention studies that assess the effect of changes in water storage and/or treatment on health outcomes.*

Odds ratios were used to examine the effects of household water treatment and storage interventions on diarrhoea and cholera. Odds ratios as calculated in the original papers were used wherever possible. In some studies these were unavailable (Khan *et al.* 1984; Kirchhoff *et al.* 1985; Deb *et al.* 1986; Quick, 1997), and so odds ratios were derived from the total number of subjects and cases in each of the intervention and the control groups.

Meta-analysis was used to explore the variation between study results not explained by chance. The significance of this variation in study results, known as heterogeneity, can be tested statistically. Where there was no heterogeneity and the variation between studies could be explained by chance, an overall pooled odds ratios was calculated using the random effects method. Where heterogeneity existed, meta-regression based on the method of restricted maximum likelihood was used to account for possible differences in study results based on their settings and design (Thompson & Sharp 1999). Characteristics of the study setting that might influence results included the types of

Table 1 | Selected characteristics of observational studies of point-of-use water quality and its effect on general diarrhoea or cholera

Study	Bacteria	Definition of poor quality water	Sanitation	Water supply	Water storage	Setting	Age cohort	Outcome
Black <i>et al.</i> 1982*	<i>E. coli</i>	N/A	N/A	Tubewells, rivers, canals, reservoirs	N/A	Rural	6–30 months	General diarrhoea
Echeverria <i>et al.</i> 1987	<i>E. coli</i>	Positive samples	N/A	Standpipes	Clay jars	Urban	<5 years	General diarrhoea
Estey <i>et al.</i> 1986	Thermotolerant coliforms; faecal streptococci	> 9 bacteria/100 ml; > 99 bacteria/100 ml	N/A	Mostly unimproved but also taps and handpumps	Buckets	Rural	1–60 months	General diarrhoea
Genthe <i>et al.</i> 1997	<i>E. coli</i> ; thermotolerant coliforms	Positive samples	88% used pit latrines/flush toilets	> 90% used standpipes	Plastic containers, mostly open	Urban	Pre-school	General diarrhoea
Han <i>et al.</i> 1991	Thermotolerant coliforms	> upper tercile bacteria count	N/A	Rainwater, standpipes, tubewells, shallow wells, ponds	N/A	N/A	6–29 months	General diarrhoea
Henry & Rahim 1990	Thermotolerant coliforms	> 10,000 bacteria/100 ml	Pit latrines/latrines over ponds	10 public tubewells; surface water	N/A	Urban	1–6 years	General diarrhoea
Henry <i>et al.</i> 1990	Thermotolerant coliforms	> median bacteria count	Some used latrines	Handpumps; unprotected sources	N/A	Rural	6–23 months	General diarrhoea
Jagals <i>et al.</i> 1997*	Thermotolerant coliforms	N/A	Pit latrines	Standpipes	10–25 l metal/plastic containers	Urban	All ages	General diarrhoea
Knight <i>et al.</i> 1992	Thermotolerant coliforms	Positive samples	69% used pit latrines	75% used wells	Mixture of wide and narrow-necked vessels	Rural	4–59 months	General diarrhoea

Continued

Table 1 | Continued

Study	Bacteria	Definition of poor quality water	Sanitation	Water supply	Water storage	Setting	Age cohort	Outcome
Lloyd-Evans <i>et al.</i> 1984	<i>E. coli</i>	Positive samples	Pit latrines	Public standpipes	Jars	Urban	6–18 months	General diarrhoea
Rajasekaran <i>et al.</i> 1975	Thermotolerant coliforms	> 10 bacteria/100 ml	In-house latrines	Open well	N/A	Rural	< 5 years	General diarrhoea
Vanderslice & Briscoe 1995*	Thermotolerant coliforms	N/A	75% used flush toilet/latrine; inadequate for rest	90% used protected sources	50% of containers had spigot	Rural	0–12 months	General diarrhoea
Deb <i>et al.</i> 1982	<i>V. cholerae</i>	Positive samples	'not satisfactory'	Ponds, tubewells, standpipes, shallow wells	Uncovered buckets	Urban	All ages	Cholera
Gunn <i>et al.</i> , 1981	<i>V. cholerae</i>	Positive samples	Flush toilets	Taps	20-litre storage containers, pitchers, jugs	Urban	All ages	Cholera
Spira <i>et al.</i> 1980	<i>V. cholerae</i>	Positive samples	N/A	43% used tubewells and the rest surface water	N/A	Rural	All ages	Cholera
Sengupta <i>et al.</i> , 1995	<i>V. cholerae</i>	Positive samples	N/A	Standpipes, open wells, tubewells, ponds	N/A	Urban	> 5 years	Cholera

* Indicates studies not included in statistical analysis; N/A indicates information not available.

water source and storage vessels present, sanitation facilities, and whether the setting was urban or rural. For observational studies, design characteristics included the type of indicator bacteria used and threshold bacteria count for defining poor quality water. For intervention studies, the nature of the intervention was recorded. For all studies, the cohort studied and case definitions for diarrhoea and for cholera were also recorded. Finally, whether or not the study was published in a refereed journal was used as a measure of the quality of each of the studies.

Publication bias occurs where smaller studies are more likely to be published if their results are significant. In this context, studies involving limited numbers of subjects might be more likely to be published when they showed a significant effect of an intervention or a significant relationship between health outcomes and bacteria counts in water samples. If such bias occurred, the pooled odds ratios would appear larger and be more likely to show significance. The resulting data sets were therefore tested for publication bias using Egger's test (Egger *et al.* 1997).

RESULTS

Studies included in the review were undertaken in 16 countries and the region with the greatest number of studies was south-east Asia. For each of the two types of study, the results are given below.

Observational studies that relate microbiological indicators of water quality at point-of-use to health outcomes (16 studies)

The characteristics of these studies are summarised in Table 1. With one exception (Jagals *et al.* 1997) all of the included studies assessed stored water quality in relation to general diarrhoea among pre-school children or sub-categories of pre-school children (Rajasekaran *et al.* 1977; Lloyd-Evans *et al.* 1984; Esrey *et al.* 1986; Echeverria *et al.* 1987; Henry & Rahim 1990; Henry *et al.* 1990; Han *et al.* 1991; Knight *et al.* 1992; Genthe *et al.* 1997). Cholera studies (Spira *et al.* 1980; Gunn *et al.* 1981; Deb *et al.* 1982; Sengupta *et al.* 1995) considered either all household

members or only those aged over 5 years. Three studies presented results in too brief a form to be usable in the meta-analysis (Black *et al.* 1982; Vanderslice & Briscoe 1993; Jagals *et al.* 1997). Egger's test suggested no evidence of publication bias in either the cholera or the diarrhoea studies.

Figure 1(a) shows the odds ratios of studies that compared point-of-use water quality with diarrhoea. A test for heterogeneity suggested that there was no significant variation between the different studies of general diarrhoea. The estimate of the pooled odds ratio (the 'overall' study line on the right of the graph) for all of the studies was 1.12 (confidence limits 0.85–1.48), suggesting no significant association between the indicator bacteria used (*E. coli* and thermotolerant coliforms) and general diarrhoea. For cholera, Figure 1(b), there was again no evidence of significant variation between studies. The pooled odds ratio of 5.6 (confidence limits 3.2–9.8) suggested significant association between *V. cholerae* in point-of-use drinking water and cholera among subjects.

Intervention studies that assess the effect of changes in water storage and/or treatment on health outcomes (12 studies)

The characteristics of the intervention studies are summarised in Table 2. There was no evidence of publication bias. Figures 2(a) and 2(b) show the effectiveness of water treatment and handling interventions, as measured by the odds ratio for diarrhoea and cholera. Three intervention studies were concerned with cholera. Of these, two considered cholera among all age groups (Khan *et al.* 1984; Deb *et al.* 1986) and one considered cholera among children under 5 years (Conroy *et al.* 2001). There was no significant heterogeneity between these intervention studies of cholera and the pooled odds ratio across all studies was 0.35 (confidence limits 0.21–0.56).

Of the general diarrhoea studies, we were unable to contact the author of one study (Austin 1994) that failed to find a significant effect of chlorination. This study presented results too briefly to be usable in the meta-analysis. We were also unable to locate a copy of an unpublished report that found a significant reduction in diarrhoea following a ceramic filter intervention (Wilson

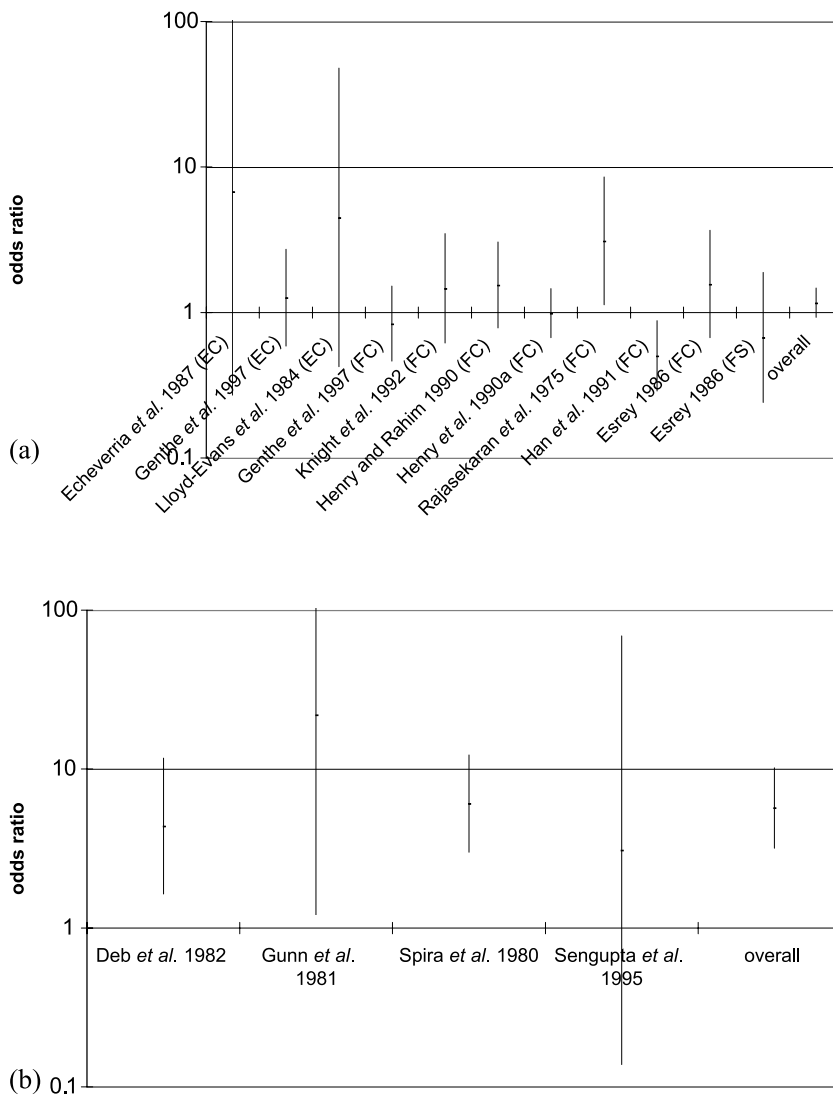


Figure 1 | (a) Odds ratios for bacteria counts in point-of-use drinking water and general diarrhoea (EC: *E. coli*; FC: faecal (thermotolerant) coliforms; FS: faecal streptococci; odds ratios above 1 indicate a positive association between drinking water quality and diarrhoea). (b) Odds ratios for *V. cholerae*-positive water samples at point-of-use and cholera cases (odds ratios above 1 indicate a positive association between drinking water quality and diarrhoea).

& Neveu 1995). Of the remaining studies, three considered general diarrhoea among all age groups (Kirchhoff *et al.* 1985; Semenza *et al.* 1998; Quick *et al.* 1999). Two studies considered general diarrhoea in children under 5 years (Mahfouz *et al.* 1995; Conroy *et al.* 1999) and two considered general diarrhoea among older children (Conroy *et al.* 1996; Quick 1997).

For these studies of general diarrhoea, significant heterogeneity was revealed, with between-studies variance of

0.095. As shown in Table 3, the proportion of households in the trial with adequate sanitation was significantly associated with greater intervention effectiveness. No other aspect of study setting showed a significant relationship. After inclusion of a sanitation variable and a constant, the residual between-studies variance was 0.06, which is still significant, suggesting that other untested characteristics of study settings and/or design may be contributing to the variation in the results.

Table 2 | Selected characteristics of reviewed intervention studies

Study	Intervention	Blinding	Sanitation	Water supply	Water storage	Setting	Age cohort	Outcome
Austin 1994*	Chlorination	Yes	N/A	Open wells	Earthenware vessels	Rural	6–60 months	General diarrhoea
Conroy <i>et al.</i> 1996	Solar disinfection	Yes	None	Open water-holes/ piped supply	N/A	Rural	5–16 years	General diarrhoea
Conroy <i>et al.</i> 1999	Solar disinfection	Yes	None	11 protected and unprotected sources	N/A	Rural	< 5 years	General diarrhoea
Kirchhoff <i>et al.</i> 1985	Chlorination	Yes	None	Pond	Clay pots	Rural	All ages	General diarrhoea
Mahfouz <i>et al.</i> 1995	Chlorination	No	Flush latrines/ septic tanks	Shallow wells	Underground/ roof tanks	Rural	< 5 years	General diarrhoea
Quick 1997	Improved vessel, chlorination and hygiene education	No	N/A	N/A	N/A	Urban	< 15 years	General diarrhoea
Quick <i>et al.</i> 1999	Improved vessel, chlorination and hygiene education	No	47% used latrines; others used open ground	Mostly shallow wells	Mostly wide- mouthed containers	Rural	All ages	General diarrhoea
Semenza <i>et al.</i> 1998	Improved vessel, chlorination and hygiene education	No	Latrines	Communal standpipes/wells	N/A	Urban	All ages	General diarrhoea
Wilson & Neveu 1995*	Water filter/water filter and hygiene education	No	N/A	N/A	N/A	Mixed	< 5 years	General diarrhoea
Conroy <i>et al.</i> 2001	Solar disinfection	No	None	11 protected and unprotected sources	N/A	Rural	All ages	Cholera
Deb <i>et al.</i> 1986	Chlorination/ improved storage	No	> 90% used service- type or sanitary latrine	> 90% used taps and tubewells	Buckets	Urban	All ages	Cholera
Khan <i>et al.</i> 1984	Alum potash	No	N/A	N/A	N/A	N/A	All ages	Cholera

* Indicates health outcome data unavailable for statistical analysis; N/A indicates data not available.

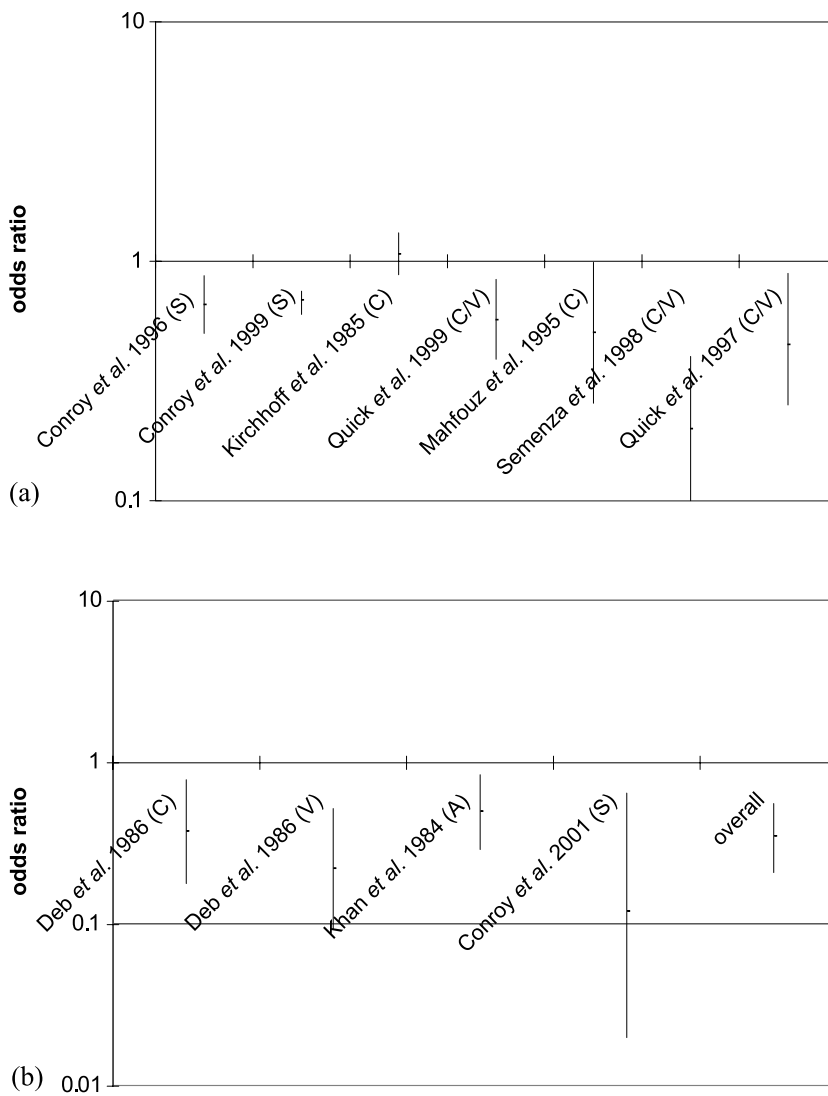


Figure 2 | (a) Odds ratios showing the effect of water treatment and storage interventions on general diarrhoea (the proportion of households with adequate sanitation increases from left to right; odds ratios below one indicate a reduction in cases in the intervention group relative to the control group; interventions are C: chlorination, V: special vessel, S: solar disinfection). (b) Odds ratios showing the effect of water treatment and storage interventions on cholera (odds ratios below one indicate a reduction in cases in the intervention group relative to the control group; interventions are C: chlorination, V: special vessel, A: alum potash, S: solar disinfection).

DISCUSSION

In terms of cholera, the findings of the studies reviewed here are straightforward. Samples of stored water testing positive for *V. cholerae* have consistently been associated with cholera cases. Interventions involving water treatment or improved storage have successfully prevented cholera. The policy implications are clear: where a developing country has a history of cholera outbreaks,

Table 3 | Meta-regression results for six studies of the effect of home water treatment on general diarrhoea (residual between-studies variance=0.06)

Variable	Coefficient
Proportion of households with adequate sanitation	- 0.88 (- 1.52, - 0.24)
Constant	- 0.23 (- 0.52, 0.07)

consideration should be given to introducing water treatment and storage at household level.

In terms of general diarrhoea, the role of point-of-use water quality appears more complex. One apparent contradiction in the studies reviewed is that most of the water treatment and storage interventions were effective, and yet high indicator bacteria counts were seldom associated with diarrhoea among subjects.

Several explanations may account for the apparently contradictory findings concerning general diarrhoea:

1. Unlike cholera, which results from infection with a single type of bacteria, a wide variety of pathogens (rotavirus, astrovirus, cryptosporidium, etc.) are responsible for diarrhoea. Counts of indicator bacteria such as thermotolerant coliforms may not be a good proxy measure of these pathogens, thus accounting for the apparent absence of a relationship between point-of-use water quality and diarrhoea (Gleeson & Gray 1997; Hamer *et al.* 1998). Had the studies used enterococci, as noted in Moe *et al.* (1991), there may have been a stronger relationship. Overall, this explanation of mismatch between water quality indicators and diarrhoeal pathogens is highly credible.
2. It may be that study participants and field workers were aware that water treatment or storage interventions were intended to reduce diarrhoea and modified their responses to conform with the anticipated outcome. Some studies did 'blind' the study participants and field workers to the nature of the intervention. In the solar disinfection studies, control households were asked to store water vessels indoors as a form of 'blinding'. In two chlorination studies, control households were given a chlorine placebo (Kirchhoff *et al.* 1985; Austin 1994). In general, however, it should be noted that 'blinding' is impossible in practice where the intervention includes use of an improved container.
3. Since most interventions also involve some form of hygiene education or otherwise raise awareness of water handling and its importance, this education—rather than better water quality *per se*—may reduce diarrhoea. Two studies have been

designed to compare the effects of hygiene education alone against hygiene education and water treatment (Wilson & Neveu 1995; Luby *et al.* 1998). These studies suggest that whilst additional the water treatment intervention undoubtedly improves water quality more than hygiene education alone, there may only be a slight reduction in diarrhoea associated with water treatment and education compared with hygiene education alone. However, one study of solar disinfection of water (Conroy *et al.* 2001) suggested that *only* the children drinking the disinfected water were at lower risk of cholera. Other household members, who may have benefited more generally from hygiene education associated with the intervention, did not drink disinfected water and showed no reduced risk of cholera. Furthermore, a recent study noted a significant reduction in diarrhoea prevalence following a chlorination and safe storage intervention, despite the absence of any hygiene education (Sobsey *et al.* 2003).

4. As suggested by Vanderslice & Briscoe (1993) other faecal-oral pathways (e.g. food, hands, etc.) may be more important than water. Several authors have found significant relationships between bacterial contamination of foods (Black *et al.* 1982) and hands (Henry & Rahim 1990) with diarrhoea morbidity, but not with bacterial counts in stored water. Given that the water treatment and storage interventions are generally effective, this explanation seems unlikely.

The studies of general diarrhoea used a wide range of definitions of 'high' and 'low' water quality. No attempt was made to adjust the analysis for the inconsistency in these definitions, since this would have entailed obtaining the raw data sets from the authors of all the studies reviewed. However, the absence of any significant heterogeneity between studies suggests that the use of different definitions of water quality does not affect the strength of the relationship with general diarrhoea. In other words, no relationship was identified between point-of-use water quality and general diarrhoea in the studies described here—*regardless* of the 'low'/'high' water quality distinction used.

The meta-regression shown in Table 3 suggested that point-of-use interventions had a greater impact on general diarrhoea where a high proportion of households had adequate sanitation. This may be because household sanitation has restricted the faecal-oral pathways associated with faecal matter around the household compound and in communal defecation areas, so reducing diarrhoea morbidity, with the consequence that an additional intervention has a proportionately greater effect. Ideally, this argument could have been examined by including absolute diarrhoea rates as a characteristic of the study setting in the meta-regression. However, not all studies presented baseline diarrhoea data. Recall periods greater than 48 h are also known to reduce reported diarrhoea rates (Blum & Feachem 1983). In the intervention studies, only the solar disinfection studies by Conroy *et al.* (1996, 1999) used a recall period greater than 48 h. The other intervention types all used recall periods of 48 h or less. As the meta-regression included 'type of intervention' as a variable, this was equivalent to testing for 'recall period in excess of 48 h'. As 'type of intervention' was not significant, it can be concluded that effect of the difference in recall periods was also insignificant.

This review of intervention trials also suggests several areas of uncertainty and in particular supports Sobsey's (2002) conclusion that there is a need for additional field studies about point-of-use interventions. Bacteriological evidence suggests that improved water vessels may be effective at reducing coliform counts in stored water where sources are well protected and consistently uncontaminated (Hammad & Dirar 1982; Pinfold 1990; Chidavaenzi *et al.* 1998). However, the impact of such improved container designs on diarrhoea outcomes needs to be determined. As with the microbiological testing, there are also several water treatment and storage interventions whose effectiveness in combating diarrhoea and/or cholera has never been demonstrated through community-based trials. In particular, various examples of household filters are in use in developing countries (Sobsey 2002), but there were no published field studies of their effectiveness in the review period. Other such interventions include the use of ground seeds from the Moringa tree, which has been shown in a laboratory study to clarify water (Kumar & Gopal 1999). Similarly, the 'three pot'

system, as promoted by Skinner & Shaw (1998) allows stored water to settle for 48 h before consumption, thus reducing pathogens in the water through sedimentation and die-off. However, to date there has been no peer-reviewed evaluation of this system. As attempted in one study (Wilson & Neveu 1995), it may also be useful to assess the role of hygiene education alone compared to hygiene education *and* water treatment or storage improvements, given that it is unclear how far hygiene education contributes to the apparent health benefits of such interventions.

Although further research is needed in some areas covered by this review, the findings indicate that water policy in developing countries may need to pay greater attention to the water quality at the point of use, if diarrhoeal morbidity is to be reduced. This implies that consideration should be given to the factors that result in post-source contamination and to methods of combating these, some of which may have more general benefits in terms of the environmental health of communities. In essence, a more 'holistic' approach to community water, sanitation and hygiene may produce better health outcomes than water source improvements alone.

ACKNOWLEDGEMENTS

This research was funded by the European Union INCO-DEV programme (Project Ref: ICA4-CT-2000-30039). The authors acknowledge the comments of Mrs Bettina Genthe and the two anonymous reviewers of an earlier draft. They also acknowledge the assistance of Ms Hannah Bird, Ms Kirsty Forbes, Ms Siobhan Kehoe and Mr Misheck Kirimi in locating relevant literature. The additional information provided by the authors of the studies is also acknowledged.

REFERENCES

- Austin C. J. 1994 *Chlorinating household water in the Gambia*. Paper presented at the 20th WEDC conference, Colombo, Sri Lanka, 1994.
- Black, R. E., Brown, K. H., Becker, S., Alim, A. R. & Merson, M. H. 1982 Contamination of weaning foods and transmission of

- enterotoxigenic *Escherichia coli* diarrhoea in children in rural Bangladesh. *Trans. R. Soc. Trop. Med. Hyg.* **76**, 259–264.
- Blum, D. & Feacham, R. 1983 Measuring the impact of water supply and sanitation investments on diarrhoeal diseases: problems of methodology. *Int. J. Epidemiol.* **20**, 1073–1080.
- Chidavaenzi, M. T., Jere, M., Nhandara, C., Chingundury, D. & Bradley, M. 1998 *An evaluation of water urns to maintain domestic water quality*. Paper presented at the 24th WEDC conference, Islamabad, Pakistan, 1998.
- Conroy, R. M., Elmore-Meehan, M., Joyce, T., McGuigan, K. G. & Barnes, J. 1996 Solar disinfection of drinking water and diarrhoea in Maasai children: a controlled field trial. *Lancet* **348**, 1695–1697.
- Conroy, R. M., Meehan, M. E., Joyce, T., McGuigan, K. & Barnes, J. 1999 Solar disinfection of water reduces diarrhoeal disease: an update. *Arch. Dis. Child* **81**, 337–338.
- Conroy, R. M., Meehan, M. E., Joyce, T., McGuigan, K. & Barnes, J. 2001 Solar disinfection of drinking water protects against cholera in children under 6 years of age. *Arch. Dis. Child* **85**, 293–295.
- Deb, B. C., Sircar, B. K., Sengupta, P. G., De, S. P., Sen, D., Saha, M. R. & Pal, S. C. 1982 Intra-familial transmission of *Vibrio cholerae* biotype E1 Tor in Calcutta slums. *Ind. J. Med. Res.* **76**, 814–819.
- 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. & Pal, S. C. 1986 Studies on interventions to prevent El Tor cholera transmission in urban slums. *Bull. World Hlth Org.* **64**, 127–131.
- Echeverria, P., Taylor, D. N., Seriwatana, J., Leksomboon, U., Chaicumpa, W., Tirapat, C. & Rowe, B. 1987 Potential sources of enterotoxigenic *Escherichia coli* in homes of children with diarrhoea in Thailand. *Bull. World Hlth Org.* **65**, 207–215.
- Egger, M., Smith, G. D., Schneider, M. & Minder, C. 1997 Bias in meta-analysis detected by a simple, graphical test. *Brit. Med. J.* **315**, 629–634.
- Esrey, S. 1996 Water, waste and well-being: a multi-country study. *Am. J. Epidemiol.* **143**(6), 608–623.
- Esrey, S. A. & Habicht, J. P. 1986 Epidemiologic evidence for health benefits from improved water and sanitation in developing countries. *Epidemiol. Rev.* **8**, 117–128.
- Esrey, S. A., Feacham, R. G. & Hughes, J. M. 1985 Interventions for the control of diarrhoeal diseases among young children: improving water supplies and excreta disposal facilities. *Bull. World Hlth Org.* **63**(4), 757–772.
- Esrey, S. A., Habicht, J. P., Casella, G., Miliotis, D., Kidd, A. H., Collett, J., Qheku, V. & Latham, M. C. 1986 Infection, diarrhoea, and growth rates of young children following the installation of village water supplies in Lesotho. In: *Proceedings of the International Symposium on Water-related Health Issues*, Atlanta, GA, American Water Resources Association, pp. 11–16.
- Esrey, S. A., Potash, J. B., Roberts, L. & Shiff, C. 1991 Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. *Bull. World Hlth Org.* **69**(5), 609–621.
- Genthe, B., Strauss, N., Seager, J., Vundule, C., Maforah, F. & Kfir, R. 1997 The effect of type of water supply on water quality in a developing community in South Africa. *Wat. Sci. Technol.* **35**, 35–40.
- Gleeson, C. & Gray, N. 1997 *The Coliform Index and Waterborne Disease. Problems of Microbial Water Assessment*. E. & F. N. Spon, London.
- Gunn, R. A., Kimball, A. M., Mathew, P. P., Dutta, S. R. & Rifaat, A. H. 1981 Cholera in Bahrain: epidemiological characteristics of an outbreak. *Bull. World Hlth Org.* **59**, 61–66.
- Hamer, D. H., Simon, J., Thea, D. M. & Keusch, G. 1998 *Childhood Diarrhoea in Sub-Saharan Africa*, pp. 1–32. Harvard University, Harvard.
- Hammad, Z. H. & Dirar, H. A. 1982 Microbiological examination of sebeel water. *Appl. Environ. Microbiol.* **43**, 1238–1243.
- Han, A. M., Oo, K. N., Aye, T. & Hlaing, T. 1991 Bacteriological studies of food and water consumed by children in Myanmar. 2. Lack of association between diarrhoea and contamination of food and water. *J. Diarrhoeal Dis. Res.* **9**, 91–93.
- Henry, F. J. & Rahim, Z. 1990 Transmission of diarrhoea in two crowded areas with different sanitary facilities in Dhaka, Bangladesh. *J. Trop. Med. Hyg.* **93**, 121–126.
- Henry, F. J., Huttly, S. R., Patwary, Y. & Aziz, K. M. 1990 Environmental sanitation, food and water contamination and diarrhoea in rural Bangladesh. *Epidemiol. Infect.* **104**, 253–259.
- Jagals, P., Grabow, W. & Williams, E. 1997 The effects of supplied water quality on human health in an urban development with limited basic subsistence facilities. *Water SA* **23**, 373–378.
- Khan, M., Khan, M., Hossain, B. & Ahmed, S. 1984 Letter: Alum potash in water to prevent cholera. *Lancet* **2**, 1032–1032.
- Kirchhoff, L. V., McClelland, K. E., Do Carmo, P. M., Araujo, J. G., de Sousa, M. A. & Guerrant, R. L. 1985 Feasibility and efficacy of in-home water chlorination in rural north-eastern Brazil. *J. Hyg. (Lond.)* **94**, 173–180.
- Knight, S. M., Toodayan, W., Caique, W. C., Kyi, W., Barnes, A. & Desmarchelier, P. 1992 Risk factors for the transmission of diarrhoea in children: a case-control study in rural Malaysia. *Int. J. Epidemiol.* **21**, 812–818.
- Kumar, S. & Gopal, K. 1999 Screening of plant species for inhibition of bacterial population of raw water. *J. Environ. Sci. & Hlth Part A—Toxic/Hazardous Substances & Environmental Engineering* **34**(iv), 975–987.
- Lloyd-Evans, N., Pickering, H. A., Goh, S. G. & Rowland, M. G. 1984 Food and water hygiene and diarrhoea in young Gambian children: a limited case control study. *Trans. R. Soc. Trop. Med. Hyg.* **78**, 209–211.
- Luby, S., Agboatwalla, M., Raza, A., Mintz, E. D., Sobel, J., Hussain, S., Husan, R., Ghouri, F., Baier, K. & Gangarosa, G. 1998 *Microbiologic evaluation and community acceptance of a plastic water storage vessel, point-of-use water treatment, and handwashing in Karachi, Pakistan*. Paper presented at the 47th Annual EIS Conference, Atlanta, GA, 1998.
- Mahfouz, A. A., Abdel-Moneim, M., Al Erian, R. A. & 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**, 126–130.
- Mintz, E. D., Reiff, F. M. & Tauxe, R. V. 1995 Safe water treatment and storage in the home. A practical new strategy to prevent waterborne disease. *JAMA* **273**, 948–953.
- Moe, C. L., Sobsey M. D., Samsa G. P. & Mesolo V. 1991 Bacterial indicators of risk of diarrhoeal disease from drinking-water in the Philippines. *Bull. World Hlth Org.* **69**(3), 305–317.
- Musa, H. A., Shears, P., Kafi, S. & Elsabag, S. K. 1999 Water quality and public health in northern Sudan: a study of rural and peri-urban communities. *J. Appl. Microbiol.* **87**, 676–682.
- Pinfold, J. V. 1990 Faecal contamination of water and fingertip-rinses as a method for evaluating the effect of low-cost water supply and sanitation activities on faeco-oral disease transmission. II. A hygiene intervention study in rural north-east Thailand. *Epidemiol. Infect.* **105**, 377–389.
- Quick, R. E. 1997 *A new strategy for waterborne disease prevention*. Paper presented at the 23rd WEDC conference, Durban, S. Africa, 1997.
- Quick, R. E., Venczel, L.V., Mintz, E. D., Soletto, L., Aparicio, J., Gironaz, M., Hutwagner, L., Greene, K., Bopp, C., Maloney, K., Chavez, D., Sobsey, M. & Tauxe, R.V. 1999 Diarrhoea prevention in Bolivia through point-of-use water treatment and safe storage: a promising new strategy. *Epidemiol. Infect.* **122**, 83–90.
- Rajasekaran, P., Dutt, P. R. & Pisharoti, K. A. 1977 Impact of water supply on the incidence of diarrhoea and shigellosis among children in rural communities in Madurai. *Ind. J. Med. Res.* **66**, 189–199.
- Semenza, J. C., Roberts, L., Henderson, A., Bogan, J. & Rubin, C. H. 1998 Water distribution system and diarrhoeal disease transmission: a case study in Uzbekistan. *Am. J. Trop. Med. Hyg.* **59**, 941–946.
- Sengupta, P. G., Sircar, B. K., Mandal, S. K., Mukhopadhyay, A. K., Nair, G. B., Gupta, D. N., Ghosh, S., Saha, N. C., Deb, B. C., Sikder, S. N., Manna, B., Bhattacharya, S. K., De, S. P. & Mandal, B. K. 1995 Epidemiology of *Vibrio cholerae* 0139 with special reference to intrafamilial transmission in Calcutta. *J. Infect.* **31**, 45–47.
- Skinner, B. & Shaw, R. 1998 Technical Brief No. 58: Household water treatment I. *Waterlines* **17**, 15–18.
- Sobsey, M.D. 2002 *Managing water in the home: accelerated health gains from improved water supply*. World Health Organisation report ref: WHO/SDE/WSH/02.07, Geneva.
- Sobsey, M. D., Handzel, T. & Venczel, L. 2003 Chlorination and safe storage of household drinking water in developing countries to reduce waterborne disease. *Wat. Sci. Technol.* **47**(3), 221–228.
- Spira, W. M., Khan, M. U., Saeed, Y. A. & Sattar, M. A. 1980 Microbiological surveillance of intra-neighbourhood E1 Tor cholera transmission in rural Bangladesh. *Bull. World Hlth Org.* **58**, 731–740.
- Thompson, S. G. & Sharp, S. J. 1999 Explaining heterogeneity in meta-analysis: a comparison of methods. *Stat. Med.* **18**, 2693–2708.
- Vanderslice, J. & Briscoe, J. 1993 All coliforms are not created equal—a comparison of the effects of water source and in-house water contamination on infantile diarrhoeal disease. *Wat. Resour. Res.* **29**, 1983–1995.
- Verweij, P. E., van Egmond, M., Bac, D. J., van der Schroeff, J. G. & Mouton, R. P. 1991 Hygiene, skin infections and types of water supply in Venda, South Africa. *Trans. R. Soc. Trop. Med. Hyg.* **85**, 681–684.
- WHO 2002 *Guidelines for Drinking-water Quality* (Second edition). *Addendum Microbiological Agents in Drinking Water*. World Health Organisation, Geneva.
- WHO/UNICEF 2000 *Global Water Supply and Sanitation Assessment 2000 Report*. World Health Organisation, Geneva.
- Wilson, D. & Neveu, M. 1995 *Clay water filters and health prevention: the road to diarrhoea prevention and better health*. Universidad Rafael Landivar, Guatemala City.