Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis

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Many studies have reported the results of interventions to reduce illness through improvements in drinking water, sanitation facilities, and hygiene practices in less developed countries. There has, however, been no formal systematic review and meta-analysis comparing the evidence of the relative effectiveness of these interventions. We developed a comprehensive search strategy designed to identify all peer-reviewed articles, in any language, that presented water, sanitation, or hygiene interventions. We examined only those articles with specific measurement of diarrhoea morbidity as a health outcome in non-outbreak conditions. We screened the titles and, where necessary, the abstracts of 2120 publications. 46 studies were judged to contain relevant evidence and were reviewed in detail. Data were extracted from these studies and pooled by meta-analysis to provide summary estimates of the effectiveness of each type of intervention. All of the interventions studied were found to reduce significantly the risks of diarrhoeal illness. Most of the interventions had a similar degree of impact on diarrhoeal illness, with the relative risk estimates from the overall meta-analyses ranging between 0·63 and 0·75. The results generally agree with those from previous reviews, but water quality interventions (point-of-use water treatment) were found to be more effective than previously thought, and multiple interventions (consisting of combined water, sanitation, and hygiene measures) were not more effective than interventions with a single focus. There is some evidence of publication bias in the findings from the hygiene and water treatment interventions.

Diarrhoeal disease is one of the leading causes of morbidity and mortality in less developed countries, especially among children aged under 5 years.[1,2] Since the seminal reviews of Esrey and colleagues in 1985, 1986, and 1991,[3–5] additional studies have been published on various water, hygiene, and sanitation-related interventions aimed at population health improvements. The original reviews,[3–5] and a study by Blum and Feachem,[6] have led to a better understanding of methodological issues in this area. The reviews by Esrey and colleagues[3–5] included studies that measured differences in health outcomes between groups that had different water or sanitation conditions.

Since these original reviews, many studies have reported additional results of interventions to reduce illness through improvements in drinking water, sanitation facilities, and hygiene practices in the less developed world. There has, however, been no formal systematic review and meta-analysis comparing the relative evidence on the effectiveness of these interventions. We present a systematic review of all published studies and, where appropriate, meta-analysis of studies that reported interventions (planned or occurring as natural experiments) in water quality, water supply, hygiene, and sanitation in less developed countries. Less developed countries are defined here as any country not within a class A region under the WHO comparative risk assessment (class A countries have very low child and adult mortality).

The meta-analyses focus on the evidence for any change arising from the interventions in diarrhoeal disease occurrence in non-outbreak conditions.

Methods

Search strategy

Database searches of the Cochrane Library, Embase, LILACS, Medline, and Pascal Biomed were done with keyword searches that paired aspects of "water", "sanitation", and "hygiene" with "diarrhoea", and, separately, with "intervention". The Cochrane Central Register of Controlled Trials was particularly useful for identifying intervention studies; Embase and Medline provided very good coverage of English language papers; and LILACS and Pascal Biomed provided coverage of foreign language, Latin American, and Caribbean papers. Searches were limited to articles published before June 26, 2003 (when the search was done), and to articles about human beings. The reviews by Esrey and colleagues[3–5] were used as an additional source to identify early studies, and author-based searches were used to identify subsequent work by the primary investigators, with additional information. All titles and abstracts (if available) from each of the searches were examined and then the relevant articles were obtained for review. Bibliographies of those articles were examined for additional references. No restrictions were put on study design, location, or language of publication.

Initial selection criteria and data extraction

Two selection criteria were used to identify articles: (1) description of specific water, sanitation, or hygiene interventions, or some combination of such interventions; and (2) diarrhoea morbidity reported as the health outcome, measured under endemic (non-outbreak) conditions. In addition, only published studies were used, to maintain quality (via peer review) and transparency.

Data on intervention effectiveness were extracted, tabulated, and, if appropriate, pooled using meta-analysis to estimate summary measures of effectiveness, expressed as the relative risk of a reduction in illness resulting from a specific type of intervention. If many articles reported results from the same study, then details of the study design were extracted from all available articles, although only the most recently published results were used in analyses.

If risk measures (including odds ratios, incidence density ratios, or cumulative incidence ratios) were not reported by the investigators, then the data were abstracted to allow the calculation of a relative risk and 95% CI by use of standard techniques.[7] If both adjusted and unadjusted measures were reported, then we used the estimate that had been adjusted for the most covariates. In all cases, the relative risk values and the 95% CI are expressed such that a relative risk of less than 1·0 indicates a reduction in the frequency of diarrhoea in the intervention group compared with the control group.

The quality of each study was examined on the basis of a set of methodological criteria for such studies previously suggested by Blum and Feachem.[6] No study was excluded from the review or meta-analysis on the basis of quality criteria alone. If possible, issues of study quality were examined in the meta-analysis as a source of possible heterogeneity between results. Poor quality studies, for the purposes of this review, were defined as those that had any of the following design flaws: inadequate or inadequately described control groups, no clear measurement or control for confounders, no specific definition of diarrhoea or the particular diarrhoeal health outcome used, or a health indicator recall period (ie, the maximum time between illness occurrence and the reporting of the illness) of more than 2 weeks. Studies without these flaws were categorised as being of good quality. Fewtrell and Colford[8] have outlined further details on issues of study quality. (Reference 8 is a 65 page report, prepared and written as part of a World Bank contract. Certain aspects, such as quality issues and pre-intervention conditions, are explored in greater detail than is possible in a journal review. Data included in the present review are based on this report.)

Interventions

There were no restrictions placed on the types of water, sanitation, and hygiene interventions in our search. We used the following classification to categorise the interventions that were identified.

Hygiene interventions were those that included hygiene and health education and the encouragement of specific behaviours, such as handwashing. Hygiene interventions could include measures as diverse as keeping animals out of the kitchen to advice on the correct disposal of human faeces.

Sanitation interventions were those that provided some means of excreta disposal, usually latrines (either public or household).

Water supply interventions included the provision of a new or improved water supply, or improved distribution (such as the installation of a hand pump or household connection). This could be at the public level or household level.

Water quality interventions were related to the provision of water treatment for the removal of microbial contaminants, either at the source or at the household level.

Multiple interventions were those which introduced water, sanitation, and hygiene (or health education) elements to the study population.

Meta-analysis

Risk estimates from the selected studies for each category of intervention were pooled in meta-analyses by use of STATA software (version 8; STATA Corporation, College Station, TX, USA). STATA commands for meta-analysis are not an integral part of the original software but are additional, user-written programs that can be downloaded from the STATA website (http://www.stata.com). Random-effects models and fixed-effects models (which both use a form of inverse variance weighting) were generated for each analysis.[9] Random effects models were used to summarise the relative risk estimates if the test of heterogeneity for a group of study results was significant (defined conservatively as $p<0\cdot20$). In the absence of heterogeneity, fixed-effects models were used. Publication bias was explored through the use of Begg's test,[10] and a result with a p value less than 0·20 was defined, a priori, to indicate the possible presence of bias.

Studies were stratified, before data analysis, into groups of related interventions (ie, hygiene, sanitation, water supply, water quality, and multiple interventions). In the main analysis, only one result from each study was used. For example, if many age-group analyses were presented in an original study, then only the combined age estimate was used in the summary estimate; or if multiple health outcomes were given, these were either combined, or if that was not possible or was inappropriate, a standard definition of diarrhoea was used, which was defined as two to four or more loose bowel movements in a 24 h period. If sufficient studies were available within each intervention, then they were further examined in subgroup analyses.

Results

The titles and abstracts (if available) from 2120 publications were screened. 50 articles,[11–60] representing 46 studies in less developed countries, were identified, of which 38 studies presented a measure of relative risk or data from which a relative risk could be calculated.[11–51] The studies were from 24 countries, with the earliest being reported in 1970.[54] Three foreign language articles were identified.[36,50,57]

The 38 usable studies were classified into the five types of interventions (figure 1). Three types of intervention were further classified into subtypes. Results for each type of intervention are shown with the estimates from each study, followed by the summary results for the meta-analyses.

Hygiene

15 articles, representing 13 distinct studies, were identified that examined hygiene interventions. 11 of these studies presented data that could be used for meta-analysis (table 1). Although the studies show a wide range of effectiveness, the summary meta-analysis suggests that hygiene interventions act to reduce diarrhoeal illness levels (random-effects model pooled estimate of relative risk 0·63, 95% CI 0·52–0·77), although there is some evidence of publication bias (Begg's test p<0·20). Re-analysis of the data after exclusion of studies thought to be of poor quality resulted in a pooled estimate of the relative risk of 0·55 (95% CI 0·40–0·75).[12,20–22]

Hygiene interventions were typically of two types, those concentrating on health and hygiene education, and those that actively promoted handwashing (usually alongside education messages). The number of messages, the content of those messages, and the way in which they were delivered varied between studies. In general, education was aimed at the mothers, although the outcome was measured in children. Separate meta-analyses examining the effectiveness of each of these specific interventions resulted in pooled estimates of relative risk of 0·56 (0·33–0·93) and 0·72 (0·63–0·83) for the effects of handwashing and education, respectively.

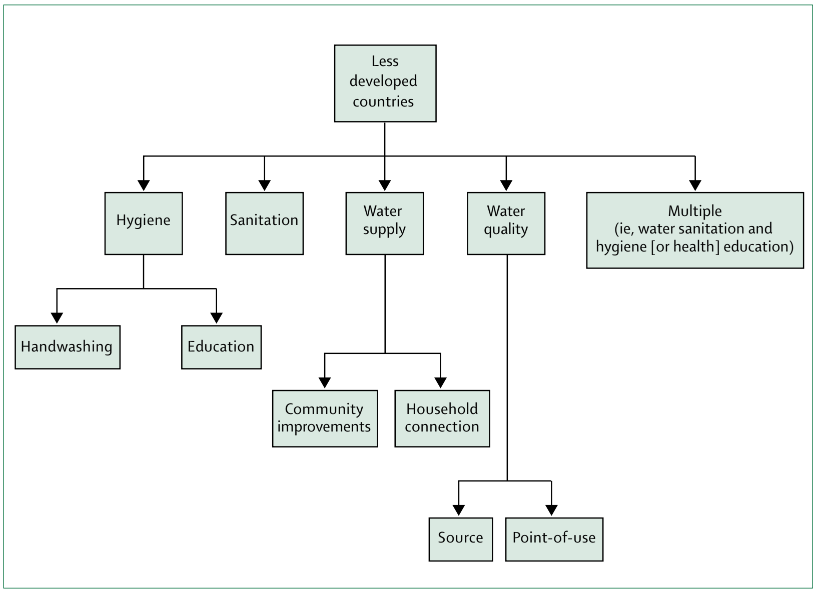

Figure 1: **Intervention stratification**

Sanitation

Four studies of the effect of sanitation interventions on health were identified. Only two of these had data that could be used in the meta-analysis (table 2). The summary meta-analysis suggests that sanitation interventions reduce illness, with a pooled relative risk of 0·68 (0·53–0·87), with no evidence of publication bias.

Water supply

It is often not possible to determine whether improvements to a water supply have improved quality or quantity, or both. For this reason, interventions were classified as water supply interventions if, for example, a new water source had been introduced, or a piped supply or household connection had been provided (table 3). Nine studies were identified, six of which could be used for meta-analysis.

The overall pooled estimate indicates that water supply interventions are effective in reducing illness (relative risk 0·75, 95% CI 0·62–0·91), with no evidence of publication bias. However, the relative risk was 1·03 (0·73–1·46) when the meta-analysis was done with only standard diarrhoea as the outcome and the ecological study was excluded.[26]

We also calculated the separate effects of household and standpipe connection on diarrhoea, which gave relative risk estimates of 0·90 (0·43–1·93) and 0·94 (0·65–1·35), respectively. Removal of the poor quality studies meant that meta-analyses were no longer possible because only one study remained in each group (table 3).

Water quality

The water quality intervention studies are shown in table 4. Most of the interventions were water treatments at the point of use (including chemical treatment, boiling, pasteurisation, and solar disinfection). The overall relative risk estimate was 0·69 (0·53–0·89), with evidence of possible publication bias. Analysis of only the studies targeting water source[31,42,45] yielded a relative risk estimate of 0·89 (0·42–1·90). Separate analysis of the household treatment studies gave a relative risk estimate of 0·65 (0·48–0·88; figure 2). The exclusion of three household treatment studies that were thought to be of poor quality[35,39,40] and the study by Xiao and colleagues[36] (for which quality information was not available) produced a relative risk estimate of 0·61 (46–0·81).

Because a relatively large number of studies on household treatment were identified, we did subgroup meta-analyses to examine the possible role of study location (rural or urban) on the effect of the intervention. Six studies were done in rural settings and the pooled relative risk estimate for household treatment from these studies was 0·61 (0·39–0·94).[32–34,36,40,44] Five studies were done in urban, peri-urban, or refugee camp environments;[35,38,39,41,43] a meta-analysis of these studies yielded a pooled

Reference	Intervention	Country (location)	Study quality*	Health outcome	Age group	Measure	Estimate (95% CI)
Khan,[11] 1982	Handwashing with soap	Bangladesh (unstated)	Good	Diarrhoea	All	RR†	0·62 (0·35–1·12)‡
Torún,[12] 1982	Hygiene education	Guatemala (rural)	Poor	Diarrhoea	0–72 months	RR†	0·81 (0·75–0·87)‡
Sircar et al,[13] 1987	Handwashing with soap	India (urban)	Good	Watery diarrhoea	0–60 months	RR†	1·13 (0·79–1·62)
					>5 years	RR†	1·08 (0·86–1·37)
				Dysentery	0–60 months	RR†	0·67 (0·42–1·09)
					>5 years	RR†	0·59 (0·37–0·93)
				Combined outcome	Combined ages	RR†	0·97 (0·82–1·16)‡
Stanton et al,[14] 1988; Stanton and Clemens,[15] 1987	Hygiene education	Bangladesh (urban)	Good	Diarrhoea	0–72 months	IDR	0·78 (0·74–0·83)‡
Alam et al,[16] 1989	Hygiene education (and increased water supply)	Bangladesh (rural)	Good	Diarrhoea	6–23 months	OR	0·27 (0·11–0·66)‡
Han and Hlaing,[17] 1989	Handwashing with soap	Burma (Myanmar) (urban)	Good	Diarrhoea	0–60 months	RR	0·70 (0·54–0·92)
					0–24 months	RR	0·69 (0·48–1·01)
					25–60 months	RR	0·67 (0·45–0·98)
				Dysentery	0–60 months	RR	0·93 (0·39–2·23)
					0–24 months	RR	0·59 (0·22–1·55)
					25–60 months	RR	1·21 (0·52–2·80)
				Combined outcome	0–60 months	RR†	0·75 (0·60–0·94)‡
Lee et al,[18] 1991	Hygiene education	Thailand (unstated)	Good	Diarrhoea	0–60 months	RR†	0·43 (0·32–0·56)‡
Wilson et al,[19] 1991	Handwashing with soap	Indonesia (rural)	Good	Diarrhoea	<11 years	RR†	0·21 (0·08–0·53)‡
Haggerty et al,[20,21] 1994	Hygiene education	Zaire (rural)	Poor	Diarrhoea	3–35 months	RR†	0·89 (0·80–0·98)‡
Pinfold and Horan,[22] 1996	Hygiene education	Thailand (rural)	Poor	Diarrhoea	0–60 months	RR†	0·61 (0·37–1·00)‡
Shahid et al,[23] 1996	Handwashing with soap	Bangladesh (periurban)	Good	Diarrhoea	All	IDR	0·38 (0·33–0·43)‡
					0–11 months	IDR	0·39 (0·29–0·54)
					12–23 months	IDR	0·53 (0·37–0·77)
					24–59 months	IDR	0·44 (0·34–0·59)
					5–9 years	IDR	0·27 (0·19–0·37)
					10–14 years	IDR	0·28 (0·16–0·49)
					>15 years	IDR	0·38 (0·30–0·49)

Results of the meta-analyses: fixed-effects estimate of relative risk (RR) 0·75 (95% CI 0·72–0·78); heterogeneity p<0·01; random-effects estimate of RR 0·63 (95% CI 0·52–0·77); Begg's test p=0·19. *For definition of quality see main text. †Calculated. ‡Result used for the overall meta-analysis, which provided a pooled estimate of relative risk. IDR=Incidence density ratio; OR=odds ratio.

Table 1: **Studies of hygiene interventions and health effects**

estimate of 0·86 (0·57–1·28). This result was, however, heavily influenced by the study of Sathe and colleagues,[35] and excluding this study resulted in a pooled estimate of 0·74 (0·65–0·85).

Multiple interventions

Nine studies assessed multiple concurrent interventions: the joint introduction of water, sanitation, and hygiene or health education measures. In such cases it was not possible to separate the health effects of the individual components of the intervention. Because of multiple publications (ie, the separate presentation of methods and results), seven distinct studies were identified. Relative risk measures and 95% CIs could only be obtained from five of these studies (table 5).

Reference	Intervention	Country (location)	Study quality*	Health outcome	Age group	Measure	Estimate (95% CI)
Azurin and Alvero,[24] 1974	Provision of communal latrines (also provided improved water supply)	Philippines (urban)	Poor	Cholera	All	RR†	0·32 (0·24–0·42)‡
					0–48 months	RR†	0·59 (0·43–0·81)
Daniels et al,[25] 1990	Latrine installation (and hygiene education)	Lesotho (rural)	Good	Diarrhoea	0–60 months	OR	0·76 (0·58–1·01) ‡

Results of the meta-analyses: fixed-effects estimate of relative risk (RR) 0·68 (95% CI 0·55–0·84); heterogeneity p=0·24; random-effects estimate of RR 0·68 (95% CI 0·53–0·87); Begg's test p=1·00. *For definition of quality see main text. †Calculated. ‡Result used for the overall meta-analysis, which provided a pooled estimate of relative risk. OR=odds ratio.

Table 2: **Studies of sanitation interventions and health effects**

Reference	Intervention	Country (location)	Study quality*	Health outcome	Age group	Measure	Estimate (95% CI)
Azurin and Alvero,[24] 1974	Municipal water (<50% with household connection)	Philippines (urban)	Poor	Cholera	All 0–48 months	RR† RR†	0·27 (0·20–0·36)‡ 0·39 (0·27–0·57)
Bahl,[26] 1976	Piped water and standpipes	Zambia (urban)	Poor	Diarrhoea Typhoid	All All	RR† RR†	0·63 (0·62–0·63)‡ 0·15 (0·05–0·43)
Ryder et al,[27] 1985	Improved quality and household connection	Panama (rural)	Poor	Diarrhoea	0–60 months	RR†	1·34 (1·05–1·63)‡
Esrey et al,[28] 1988	Continually functioning tap or handpump serving less than 100 households	Lesotho (rural)	Poor	Diarrhoea	1–60 months 1–12 months 13–60 months	RR† RR† RR†	1·86 (1·11–3·14)‡ 1·70 (0·84–3·43) 1·80 (0·88–3·67)
Wang et al,[29] 1989	Well with household or nearby connection	China (rural)	Good	Diarrhoea	All	RR†	0·62 (0·59–0·65)‡
Tonglet et al,[30] 1992	Piped water (standpipes)	Zaire (rural)	Good	Diarrhoea	0–48 months	RR†	0·95 (0·88–1·00)‡

Results of the meta-analyses: fixed-effects estimate of relative risk (RR) 0·63 (95% CI 0·62–0·64); heterogeneity p<0·01; random-effects estimate of RR 0·75 (95% CI 0·62–0·91); Begg's test p=0·71. *For definition of quality see main text. †Calculated. ‡Result used for the overall meta-analysis, which provided a pooled estimate of relative risk.

***Table 3:* Studies of water supply-related interventions and health effects**

The results from individual studies were all within a similar range and the results of the meta-analysis indicated that the relative risk of diarrhoea after the use of multiple interventions is 0·67 (0·59–0·76). The largest reduction in the relative risk of diarrhoea (table 5) was reported by Hoque and colleagues[49] for children aged over 5 years. Limiting the meta-analysis to children under the age of 5 or 6 years still suggests a significant decrease in illness (random-effects model pooled estimate 0·70, 0·64–0·77). The studies used various outcome measures (diarrhoea, severe diarrhoea, persistent diarrhoea, and dysentery), and multiple interventions had similar effects on severe diarrhoea and dysentery (pooled estimate of relative risk 0·68, 0·62–0·74) and on diarrhoea (pooled estimate of relative risk 0·74, 0·69–0·79).

Results summary

A summary of the meta-analysis results is shown in figure 3. Most of the categories of intervention had a similar degree of effect on diarrhoeal illness, with the relative risk estimates from the overall meta-analyses ranging between 0·63 and 0·75, with overlapping 95% CIs.

Discussion

The range of results derived from individual studies was wide, but the overall estimates seem to suggest an important role for each intervention in the reduction of diarrhoeal disease (figure 3). Previous reviews have assessed the effect of similar intervention types on the frequency of diarrhoeal illness, most notably Esrey and colleagues[5] and Curtis and Cairncross.[61] By grouping some of the categories used by Esrey and colleagues[5] and converting the reported percentage reduction in diarrhoeal illness into relative risk estimates (table 6), it is possible to compare our results with those from earlier reviews (figure 4). Our results do not contradict earlier analyses. However, this assessment suggests that water quality interventions may be more effective than previously described.

Hygiene interventions act by reducing contamination of hands, food, water, and fomites, and seem to be at least as effective as the other interventions. In our review, separate meta-analyses of handwashing (relative risk 0·56, 0·33–0·93) and hygiene education studies (relative risk 0·72, 0·63–0·83) were possible. Our results support those of Curtis and Cairncross[61] who focused on handwashing studies as opposed to general hygiene interventions and also combined results from developed and less developed countries. Despite the effectiveness of hygiene interventions in disease prevention, health considerations may be less effective at motivating people to use them than are other factors at inducing hygienic behaviours, such as the desire to feel and smell clean, and the desire to follow social norms. Therefore, Curtis and Cairncross[61] suggest that the promotion of hand soap as a desirable consumer product may be a more effective dissemination strategy than that of health campaigns.

Comparison of the results of sanitation interventions from our review with those of Esrey and colleagues[5] reveals few differences, although it is important to note that a comparison of more rigorous studies could not be done because there was only one study in this category. Given the paucity of results, this is an area that needs further research. Studies that examine the effects on diarrhoeal morbidity of ecological or dry sanitation may be of particular interest. Dry sanitation is a closed-loop system, which treats human excreta as a resource, whereby excreta are processed on site until free of pathogens and then recycled for agricultural purposes.[62] Such an approach may play an increasingly important part in future sanitation provision as the scarcity of water increases.

Reference	Intervention	Country (location)	Study quality*	Health outcome	Age group	Measure	Estimate (95% CI)
Ghannoum et al,[31] 1981	Reservoirs and chlorination	Libya (unstated)	Poor	Dysentery Giardia	All All	RR† RR†	0·41 (0·39–0·44)‡ 1·43 (0·98–2·08)
Kirchhoff et al,[32] 1985	Point-of-use water treatment (hypochlorite)	Brazil (rural)	Good	Diarrhoea	<2 years 2–4 years 5–9 years ≥10 years	RR† RR† RR† RR†	1·07 (0·88–1·30)‡ 1·16 (0·90–1·51) 0·71 (0·48–1·07) 1·80 (1·02–3·16)
Mahfouz et al,[33] 1995	Point-of-use water treatment (chlorination)	Saudi Arabia (rural)	Good	Diarrhoea	0–60 months	RR†	0·54 (0·30–0·99)‡
Conroy et al,[34] 1996	Point-of-use water treatment (solar disinfection)	Kenya (rural)	Good	Diarrhoea Severe diarrhoea	5–16 years 5–16 years	OR OR	0·66 (0·50–0·87)‡ 0·65 (0·50–0·86)
Sathe et al,[35] 1996	Point-of-use water treatment (boiling)§	India (urban)	Poor	Diarrhoea	All	RR†	2·15 (1·57–2·73)‡
Xiao et al,[36] 1997	Point-of-use water treatment (boiling) and source improvements	China (rural)	Insufficient data to judge quality	Diarrhoea	All	RR†	0·38 (0·35–0·40)‡
Semenza et al,[37] 1998	Point-of-use water treatment (disinfection and safe storage)	Uzbekistan (unstated)	Good	Diarrhoea	All <5 years	RR RR	0·15 (0·07–0·31)‡ 0·33 (0·19–0·57)
Quick et al,[38] 1999; Sobsey et al,[39] 2003	Point-of-use water treatment (disinfection and safe storage)	Bolivia (peri-urban)	Good	Diarrhoea	All	OR	0·57 (0·39–0·84)‡
Iijima et al,[40] 2001	Point-of-use water treatment (pasteurisation)	Kenya (rural)	Poor	Severe diarrhoea	All	RR†	0·56 (0·39–0·81)‡
Roberts et al,[41] 2001	Safe household storage	Malawi (refugee camp)	Good	Diarrhoea	All <5 years	RR† RR†	0·79 (0·62–1·03)‡ 0·68 (0·45–1·01)
Gasana et al,[42] 2002	Source protection and source treatment	Rwanda (unstated)	Poor	Diarrhoea	0–60 months	RR†	1·00 (0·90–1·12)‡
Quick et al,[43] 2002	Point-of-use treatment (disinfection and safe storage)	Zambia (peri-urban)	Good	Diarrhoea	All	RR	0·53 (0·30–0·93)‡
Colwell et al,[44] 2003	Point-of-use treatment (simple filtration)	Bangladesh (rural)	Good	Cholera	0–60 months	RR†	0·62 (0·46–0·83)‡
Jensen et al,[45] 2003	Source water treatment (chlorination)	Pakistan (rural)	Good	Diarrhoea	0–60 months	OR	1·99 (1·10–3·61)‡
Sobsey et al,[39] 2003	Point-of-use water treatment (disinfection and safe storage)	Bangladesh (urban)	Poor	Diarrhoea	0–60 months	IDR	0·78 (0·73–0·83)‡

Results of the meta-analyses: fixed-effects estimate of relative risk (RR) 0·56 (95% CI 0·54–0·58); heterogeneity p<0·01; random-effects estimate of RR 0·69 (95% CI 0·53–0·89); Begg's test p=0·09. *For definition of quality see main text. †Calculated. ‡Result used for the overall meta-analysis, which provided a pooled estimate of relative risk. §Various treatment types studied, boiling chosen to compare against no treatment. IDR=Incidence density ratio; OR=odds ratio.

Table 4: **Studies of water quality interventions and health effects**

There are currently too few data to disentangle satisfactorily the role of service level (ie, community *vs* household connection) and the health effect of water supply interventions. Although six studies on this issue were identified, they spanned a range of interventions. Improvements to the water source, however, often neglected the role of household storage and possible subsequent contamination. More surprisingly, studies often did not clearly record whether the provision of an improved water supply substantially changed the amount of water use, although it has been proposed that increased water supply can improve health status by enabling better hygiene.[5] An increased water supply might also improve health by decreasing the need for storage in the home and for transport. These factors should be addressed in any future research in this area.

Improving the microbial safety of water immediately before consumption seems to be very effective in reducing diarrhoeal disease (figure 3), especially when only good quality studies are examined (relative risk 0·61, 0·46–0·81). This result makes intuitive sense, and is important because many households in less

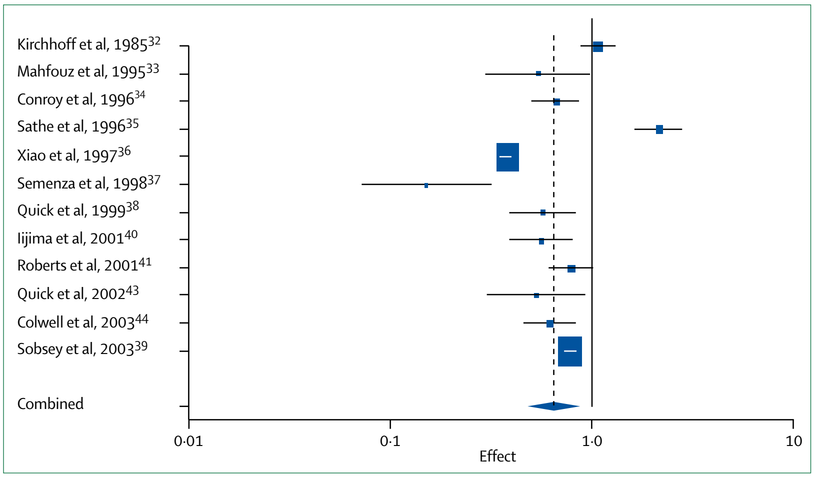

Figure 2: **Random effects meta-analysis of household treatment water quality interventions**

Reference	Intervention	Country (location)	Study quality*	Health outcome	Age group	Measure	Estimate (95% CI)
Aziz et al,[46] 1990	Handpump and latrine installation, hygiene education	Bangladesh (rural)	Good	Diarrhoea	0–60 months	IDR	0·75 (0·70–0·80)‡
				Persistent diarrhoea	0–60 months	IDR	0·58 (0·52–0·65)
				Dysentery	0–60 months	IDR	0·73 (0·61–0·88)
Mertens et al,[47,48] 1990	Tube well construction, traditional well rehabil-itation, latrine construction, health education	Sri Lanka (rural)	Good	Severe diarrhoea	0–60 months	RR	0·65 (0·58–0·72)‡
Hoque et al,[49] 1996§	Handpump and latrine installation, hygiene education	Bangladesh (rural)	Good	Diarrhoea	0–60 months	RR	0·64 (0·37–1·09)
					>60 months	RR	0·45 (0·31–0·64)
					All	RR†	0·50 (0·37–0·67)‡
Messou et al,[50] 1997	Water supply, pit latrines and health education	Côte d'Ivoire (rural)	Insufficient data to judge quality	Diarrhoea	0–60 months	RR†	0·63 (0·50–0·81)‡
Nanan et al,[51] 2003	Improve potable supply at village and household levels, sanitation, hygiene education	Pakistan (rural)	Good	Severe diarrhoea	4–71 months	OR	0·75 (0·56–0·99)‡

Results of the meta-analyses: fixed-effects estimate of relative risk (RR) 0·71 (95% CI 0·67–0·75); heterogeneity p=0·02; random-effects estimate of RR 0·67 (95% CI 0·59–0·76); Begg's test p=0·46. *For definition of quality see main text. †Calculated. ‡Result used for the overall meta-analysis, which provided a pooled estimate of relative risk. §Follow-up study, 6 years after the original intervention.[46] IDR=Incidence density ratio; OR=odds ratio.

Table 5: **Studies of multiple interventions and health effects**

developed countries do not have individual connections to treated, piped water, or 24 h access to water. Such households typically store water in the home, and this water is vulnerable to contamination (primarily from handling) during transport and storage, even if it is clean at source. The result suggests that a water quality intervention at the point of use should be considered for any water supply programme that does not provide 24 h access to a safe source of water.

The effect of multiple interventions does not seem to be additive, a phenomenon also noted by Esrey and colleauges.[5] This is perhaps surprising and disappointing, but may be caused by several factors. These include the piecemeal implementation of more ambitious intervention programmes, which may result in an overall lack of focus or lack of sufficient attention being given to those components that are thought to be less central to the programme (typically, sanitation and

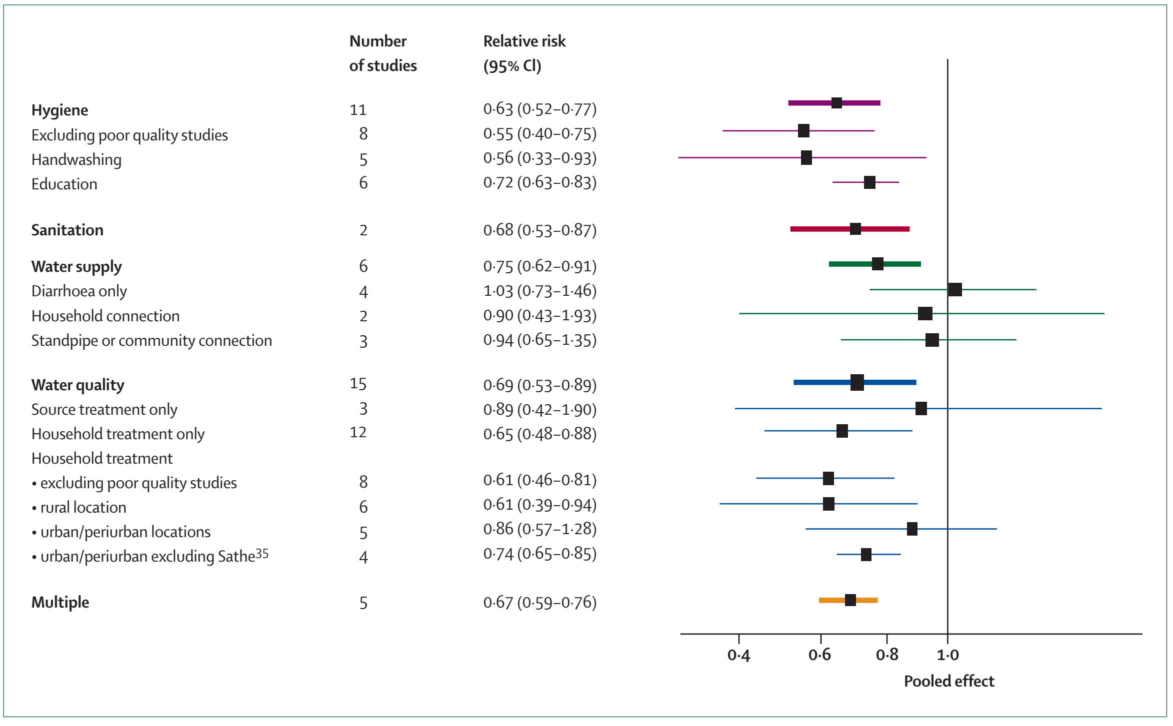

Figure 3: **Summary of meta-analysis results**

hygiene education). Also, none of the studies assured water quality at the point of consumption, which may have undermined water supply improvements. The lack of evidence of success of multiple interventions is important, because many large-scale, publicly funded interventions in less developed countries follow a model in which water supply, sanitation facilities, and hygiene education are provided even when recipients are primarily motivated by the desire to obtain a more convenient or reliable water supply. Future projects may benefit from exploring ways in which each component can be given adequate attention and focus, perhaps by implementing them in a phased manner, with emphasis placed on water quality in the household.

In general, estimates calculated after the removal of poor quality studies from the meta-analyses indicated a stronger effect of the intervention. Although some of the studies identified in this review pre-dated the methodological critiques provided by Blum and Feachem[6] and Esrey and Habicht,[4] poorly done or poorly reported studies still make up a substantial part of the literature with 32% (12 of 38) of the identified studies classified as poor, with 50% (six of 12) of these being published after 1990. In addition to the studies classified as being of poor quality, data could not be extracted from 17% (eight from 46) of the studies identified. It seems clear that this research agenda would benefit from further guidance in terms of issues to be examined, reiteration of quality considerations, and guidelines in terms of reporting and presentation of results.

In the case of the hygiene intervention studies and those examining water quality interventions, there was some evidence of possible publication bias. This raises the possibility that some studies with negative results (ie, no health benefit relating to the intervention) were not submitted or were not accepted for publication. As this is one possible explanation for the positive findings in this and other fields, it is crucial that investigators attempt to publish, and editors accept for publication, well-conceived and executed studies even when the results are negative.

In addition, hygiene and water quality interventions were generally studied for shorter periods than those relating to water supply and multiple interventions, with the collection period of health data averaging 12 months for hygiene, 9 months for water quality, and over 2 years for water supply and multiple interventions (data not shown).

The sustainability of interventions is a crucial factor. For all of the interventions reviewed here, there is little information on the longevity of health-related effects and behaviour changes after the immediate study period. Only three studies revisited study sites after the original implementation study period,[49,53,63] although each of these suggested that the intervention was still effective.

Most of the studies confined their study groups to children aged under 5 or 6 years. If possible, separate meta-analyses were done to compare the effects in children aged under 6 years with those in older age groups or the whole population (data not shown). The interventions resulted in a reduction in illness in all analyses, although for the older age groups the results were not always significant (eg, hygiene and water quality). Although this finding may mean that the results are not generalisable to all age groups, it is traditionally the younger age groups that are thought to be most vulnerable to diarrhoeal illness.[1,2]

We did observe heterogeneity in the published results (necessitating the use of random-effects models). It is possible that this reported heterogeneity in the results was due to differences in underlying risk.[9] Whereas the source of this heterogeneity cannot be determined from the data provided in the studies, we suggest that it is likely to be related, in part, to site-specific differences in culture, pre-intervention conditions, and the prevalence of different pathogens. Such heterogeneity can only be studied more effectively if investigators provide additional information on the study conditions before and after the intervention, with data about the specific pathogens that cause diarrhoea.

Given that each of the interventions reviewed seems effective, it may be reasonable to select interventions

Reference and intervention	All studies		Rigorous studies*	
	% reduction in diarrhoeal disease	Relative risk (95% CI)	% reduction in diarrhoeal disease	Relative risk (95% CI)
Esrey et al[5]				
Hygiene	33	0·67	33	0·67
Sanitation	22	0·78	36	0·64
Water supply†	22	0·78	19	0·81
Water quality	17	0·83	15	0·85
Multiple‡	20	0·80	30	0·70
Curtis and Cairncross[61]				
Handwashing§	43	0·57 (0·46–0·72)	42	0·58 (0·49–0·69)

*Studies defined by Esrey and colleagues[5] as “rigorous”, and by Curtis and Cairncross[61] as of “high methodological quality”. †Data averaged from Esrey and colleagues’ “water quality and water quantity” and “water quantity” categories. ‡Thought to be equivalent to Esrey and colleagues’ “water and sanitation” category. §The relative risk reported the risk associated with not washing hands and therefore the reciprocal has been stated here to allow comparison with the current review.

Table 6: **Reported reduction in diarrhoeal disease morbidity from improvements in one or more components of water and sanitation from previous reviews**

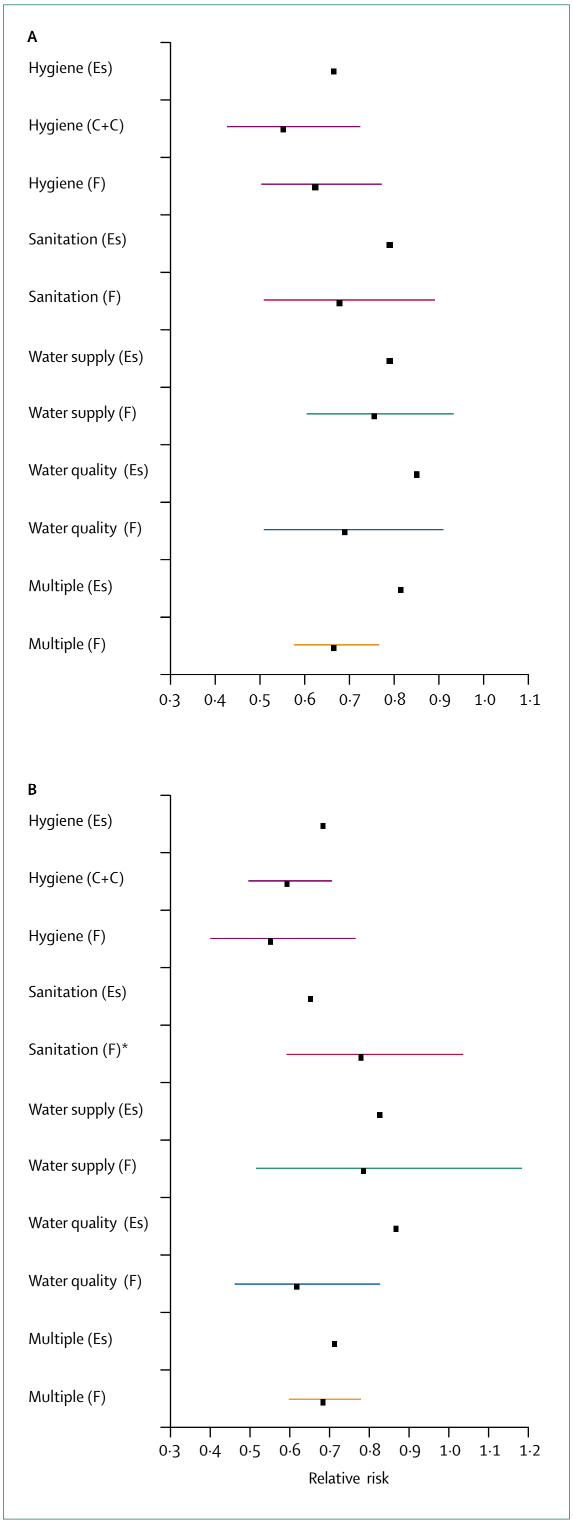

Figure 4: **Comparison of current and previous reviews**
(A) All studies. (B) Rigorous studies: defined by Esrey and colleagues (Es)[5] as "rigorous", by Curtis and Cairncross (C+C)[61] as "high methodological quality", and in current review (F) as good. *Single study and not the results of a meta-analysis. It was not possible to calculate 95% CI for data from Esrey and colleagues.[5]

for a given setting on the basis of their local desirability, feasibility, and cost-effectiveness. Although an assessment of the cost-effectiveness is beyond the scope of this review, recent studies are available.[64]

Our review focuses on the health benefits resulting from the reduction in diarrhoeal illness that relate to improvements in water, sanitation, and hygiene. Clearly, such interventions are likely to have a positive effect on other illnesses, such as schistosomiasis, ascariasis, and respiratory outcomes.[5] There may, however, be unintentional negative consequences in specific settings, such as in Bangladesh where widespread arsenic exposure is occurring as a result of wells being drilled to replace microbially contaminated surface water, because the groundwater in much of the country contains naturally occurring arsenic.[65] The making of intelligent choices of interventions for specific settings entails consideration of feasibility, cost-effectiveness, social issues, and sustainability, as well as water engineering and health issues, and often requires the combined expertise of many professional groups.

The need for careful selection of water, sanitation, and hygiene interventions should receive particular attention now given the UN Millennium Development Goals and targets for less developed countries, which aim to halve the proportion of people without sustainable access to safe water and reduce the mortality rate of children aged under 5 years by two-thirds. All 189 UN member states have pledged to meet the Millennium Development Goals by 2015, and the UN General Assembly has given them additional weight by declaring 2005–2015 to be the International Decade for Action—Water for Life. The worldwide commitment to these goals provides an excellent opportunity to improve health and quality of life through the implementation of appropriate interventions.

Conclusions

Despite the fact that the identified studies were done in a wide range of settings, in many countries, and over many years, there was found to be a strong consistency in the effectiveness of the interventions. Our review suggests that water, sanitation, and hygiene interventions, as well as their combination, are effective at reducing diarrhoeal illness, and water quality interventions (point-of-use water treatment) were more effective than has been previously acknowledged. However, publication bias may have been present in the subset of studies on water quality. Surprisingly, there was no evidence of an additive benefit from the application of concurrent multiple interventions. Detailed examination of specific interventions suggests that some aspects of the individual interventions may be more effective than

Search strategy and selection criteria

These are discussed in detail in the Methods section on page 34.

others, but there are currently too few data with which to reach firm conclusions.

This review identifies many research questions that need more attention: the role of community versus household connections within water supply interventions, the role of sanitation interventions in the reduction of diarrhoeal illness, and the longevity of the health-related effects of individual interventions. Problems with poor and inconsistent study design persist despite attention to these issues in earlier reviews.

Conflicts of interest

We have no conflicts of interest.

Acknowledgments

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